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# NATIONAL COMMUNICATIONS SYSTEM

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## TECHNICAL INFORMATION BULLETIN
## 88-7

# THE EFFECTS OF HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) ON THE NORTHERN TELECOM INC. DMS-100™ SWITCH

## VOLUME II

## TEST PROGRAM

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SEPTEMBER 1988

OFFICE OF THE MANAGER
NATIONAL COMMUNICATIONS SYSTEM
WASHINGTON, D.C. 20305

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This report is part of a three volume set that presents the results of simulated High-Altitude Electromagnetic Pulse (HEMP) testing of a Northern Telecom Inc. DMS-100 Switching System. This volume is a detailed description of the test procedures, test results, and the mitigation alternatives evaluated. This volume also presents a discussion of the conclusion and recommendations of the program. (jld)

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SEPTEMBER 1988

OFFICE OF THE MANAGER
NATIONAL COMMUNICATIONS SYSTEM
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<u>NCS TECHNICAL INFORMATION BULLETIN 88-7</u>

# THE EFFECTS OF HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) ON TELECOMMUNICATIONS ASSETS

SEPTEMBER 1988


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## FOREWORD

The National Communications System (NCS) is an organization of the Federal Government whose membership is comprised of 23 Government entities. Its mission is to assist the President, National Security Council, Office of Science and Technology Policy, and Office of Management and Budget in:

- The exercise of their wartime and non-wartime emergency functions and their planning and oversight responsibilities.
- The coordination of the planning for and provision of National Security/ Emergency Preparedness communications for the Federal Government under all circumstances including crisis or emergency.

In support of this mission the NCS has initiated and manages the Electromagnetic Pulse (EMP) Mitigation Program. The objective of this program is the removal of EMP as a significant impediment to timely reestablishment of regional and national telecommunications following an attack against the United States that includes high-altitude nuclear detonations. The program approach involves estimating the effects of High-altitude EMP (HEMP) on telecommunication connectivity and traffic handling capabilities, assessing the impact of available HEMP mitigation alternatives, and developing a comprehensive plan for implementing mitigation alternatives. This report summarizes EMP test results on the NTI DMS-100 as they apply to the EMP Mitigation Program.

Comments on this TIB are welcome and should be addressed to:


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# PREFACE

This report is part of a three volume set that presents the results of simulated High Altitude Electromagnetic pulse (HEMP) testing of a Northern Telecom Inc. DMS-100™ switching system. The efforts described herein were funded by the Office of the Manager, National Communications System (OMNCS) and were performed by US Army Harry Diamond Laboratories (HDL) and by Booz•Allen and Hamilton Inc., Northern Telecom, Inc. (NTI), and Bell Northern Research (BNR) under HDL Contract Number DAAL02-86-D-0042, Delivery Order Numbers 7, 18, 35, and 43.

The technical contributors from HDL include J. Miletta (Program Manager), R. Reyzer (Project Leader), L. Ambrose, W. Coburn, A. Hermann, C. Reiff, and D. Troxel. The technical contributors from Booz•Allen include R. Balestri, A. Bueno, R. Henrickson, D. Palleta, W. Shiley, and T. Styer. Technical contributors from NTI/BNR include A. Childerhose, D. Dowse, J. Edwards, A. Hussein, D. O'Connor, and J. Skinner.

Volume I presents a brief discussion of the test events and the test results, and summarizes the conclusions and recommendations of the test program. This volume is a detailed description of the test procedures, the test results, and the mitigation alternatives evaluated. This volume also presents a discussion of the conclusions and recommendations of the program. Volume III describes the post test analysis of the measured electromagnetic fields and induced transients. Volume III also includes a comparison of the characteristic attributes of the various simulator environments.


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## ACRONYMS

| | |
|---|---|
| AC | Alternating Current |
| AESOP | Army EMP Simulator Operation Pulser |
| BA&H | Booz•Allen & Hamilton, Inc. |
| BNR | Bell Northern Research |
| CCC | Central Control Complex |
| CMC | Central Message Controller |
| CO | Central Office |
| CPM | Central Processor And Memory |
| CPU | Central Processor Unit |
| DC | Direct Current |
| DDU | Disk Drive Unit |
| DNPC | Dual Network Packaged Core |
| DS | Data Store |
| DTM | Dual Tone Multi-frequency |
| EMI | Electromagnetic Interference |
| EMP | Electromagnetic Pulse |
| FSP | Frame Supervisory Panel |
| HDL | Harry Diamond Laboratories |
| HEMP | High-altitude Electromagnetic Pulse |
| IC | Integrated Circuit |
| IOC | Input/Output Controller |
| kV | Kilovolt |
| LCM | Line Concentrating Module |
| LTC | Line Trunk Controller |
| MAP | Maintenance and Administration Position |
| MDF | Main Distribution Frame |
| MEB | Message Exchange Bus |
| MTD | Magnetic Tape Drive |
| MTM | Maintenance Trunk Module |
| NCAM | Network Connectivity Analysis Model |
| NM | Network Module |
| NSDD | National Security Decision Directive |
| NSEP | National Security Emergency Preparedness |
| NTI | Northern Telecom Incorporated |
| OEM | Original Equipment Manufacturer |
| OMNCS | Office of the Manager, National Communications System |
| OV | Overvoltage |
| PCAM | Packaged Core Auxilliary Module |
| PCGM | Packaged Core General Module |
| PCLM | Packaged Core Line Module |
| PCM | Pulse Code Modulation |
| PCMM | Packaged Core Memory Module |
| PCSM | Packaged Core Service Module |

| | |
|---|---|
| **PCTM** | Packaged Core Trunk Module |
| **PM** | Peripheral Module |
| **PS** | Program Store |
| **PSN** | Public Switched Network |
| **PCPM** | Packaged Core Power Module |
| **REPS** | Repetitive EMP Simulator |
| **RLCM** | Remote Line Concentrating Module |
| **STM** | Service Trunk Module |
| **TEM** | Transverse Electromagnetic |
| **TM** | Trunk Module |
| **TM8** | TM-type, 8 Wires |
| **UV** | Undervoltage |

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# 1.0 INTRODUCTION

This report presents the results of testing the Northern Telecom Inc. (NTI) DMS-100[1] digital telephone switch to simulated High Altitude Electromagnetic Pulse (HEMP) fields at the U.S. Army Harry Diamond Laboratories (HDL) Woodbridge Research Facility (WRF). The test was sponsored by the Office of the Manager, National Communication System (OMNCS) to characterize the response of a typical DMS-100 switch to HEMP fields that are produced from a nuclear explosion.

The data presented in this report represent the information that is of importance to the OMNCS. This program is not meant to be a complete HEMP characterization of the DMS-100. Rather, the goal of this program is to provide data to support the OMNCS assessments of HEMP effects on networks.

## 1.1 BACKGROUND

Executive Order 12472 (E.O. 12472) and National Security Decision Directive 97 (NSDD-97) have tasked the OMNCS to address the effects of HEMP on the nation's telecommunications infrastructure during emergency conditions. In response to this task, the OMNCS supports the EMP Mitigation Program. This program focuses its energies on the potential adverse effects of the HEMP on the Public Switch Network (PSN), because the NCS member organizations rely on the PSN to fulfill the majority of their National Security Emergency Preparedness (NSEP) telecommunications requirements.

The EMP Mitigation Program methodology involves identifying critical telecommunications assets, evaluating the effects of HEMP on selected telecommunications elements, evaluating the effects of HEMP on selected telecommunication networks, using the Network Connectivity Analysis Model (NCAM), and assessing alternative strategies for mitigating the effects of HEMP. One goal of the program is to address the network-level assessment of the performance of the PSN and not that of any particular switch. To meet this goal, a statistical approach for approximating the network is adopted by the OMNCS to describe network effects.

To attain the goals of the OMNCS, the EMP Mitigation Program attempts to maximize the value of limited data available to the OMNCS. In this sense, the program is not meant to be a survivability assessment in the traditional sense. To understand the limitations, it is important to understand the constraints that the OMNCS faces. There are a large number of assets in the PSN. Although many of these assets may be of the same type, such as the DMS-100, they can be implemented in various different configurations. In addition, the OMNCS is not enpowered to force a standard configuration for each type of assets. Given these constraints, the OMNCS must attempt to prioritize the tasks and to obtain a general, network-level understanding of the HEMP response of the assets. The type of testing recommended will obtain data that are not applicable to any particular asset, but are representative of assets in the NSEP telecommunications network. The data

[1] *The term DMS-100 is used throughout this report to represent the switch tested, which was an NTI MSL-100.*

collected can then be used in a statistical method to describe these assets. In this manner, the OMNCS can maximize the value of the information that is collected.

## 1.2 OBJECTIVES

The objectives of the HEMP testing of the DMS-100 are defined by the EMP Mitigation Program. Testing of critical assets will determine their response to the HEMP environment and any possible mitigation techniques possible.

The primary objective of HEMP testing the DMS-100 is to provide data for the statistical model. Call processing capabilities of the DMS-100 are of the utmost importance to supporting NSEP initiatives. Therefore, damage and upset vulnerabilities of the DMS-100 system when exposed to the simulated HEMP environment were monitored during the test. In addition, threshold levels of these events were determined in the test.

A secondary objective of the testing is to identify mitigation alternatives, where possible. Various techniques can be used to mitigate the effects of the HEMP. Therefore, various functions of the switch were monitored to determine the source of the upset or damage.

## 1.3 TECHNICAL APPROACH

The technical approach taken in the HEMP test was selected to meet the two objectives outlined above. To meet the objectives, it is necessary to do the following:

- Determine the test article
- Simulate telecommunications traffic
- Simulate the HEMP fields
- Perform diagnostics for the switch
- Determine fixes for the possible upsets and damages.

The required test article was determined by NTI, based on the requirements of the OMNCS. The test article consisted of representative subsystems for a typical switch installation and was configured to resemble realistic interconnections between major components of a variety of switch system applications. The test article could only approximate the configuration of any fielded DMS-100 because of the numerous possible configurations of the switch. However, all important subsystems were included in the test article.

To simulate a functional switch, a "load box" was used to generate calls to and from the switch. This was also used as a diagnostic/test tool by providing printed reports of call statistics as testing progresses. In addition, the maintenance administration position (MAP), which provides a variety of alarms, status reports, and diagnostic test was used to perform diagnostics for the switch. The results of the MAP are reported on both a cathode ray tube (CRT) monitor and a printer.

Exposure of the switch to simulated HEMP took place in three major phases. The first phase was low field strength (approximately 2.5 kV/m), free field pulsed illumination test of the test article in Ottawa, Canada. Ottawa was chosen for the proximity of the Bell-Northern Research (BNR) facility where technical support personnel are located. The second phase involved shipment of the equipment to HDL, WRF, for illumination test under the HDL Repetitive EMP Simulator (REPS) simulator, at somewhat higher field levels (10 kV/m). The third phase consisted of exposing the test equipment to the threat-level field strengths, which were at the HDL (AESOP) simulator (33-70 kV/m).

With the information from the diagnostics, various combinations of circuit hardware, software, and shielding are used to mitigate the effects of the simulated EMP fields.

## 1.4 PARTICIPANTS

The organizations participating in the DMS-100 HEMP test program were OMNCS, HDL, Booz•Allen & Hamilton, Inc. (BA&H), NTI, and BNR. The OMNCS sponsored the testing and defined the test requirements, including field strengths and data to be collected. HDL, under tasking from OMNCS, acted as the test director and provided the simulators, measurement equipment, and technical expertise to generate the simulated HEMP fields. BA&H, under contract to HDL, provided technical support to HDL in the areas of test planning and test execution.

NTI, under contract to BA&H, provided the test article and technical support in the areas of test planning, system operation, and system diagnostics. The post-test analysis and documentation of test results was provided by a combination of HDL, BA&H, NTI, and BNR personnel.

## 1.5 ORGANIZATION

This report is organized to present the details of the testing, the results, mitigation techniques, recommendations, and conclusions. Section 2.0 presents a general overview of the results. This section contains a concise report of the data, for the reader who already has some background to the testing of the DMS-100.

Section 3.0 presents a background description of the testing. This included a detail discussion of the test article, the test facilities, and the instrumentation used in the test. Section 4.0 discusses the actual test. The details of the test and the configuration changes are presented. In addition, this section also gives a detail discussion of the results. Section 5.0 presents the mitigation techniques that were attempted during the test. This section gives a detail discussion of the hardware, software, and shielding configuration that were employed in the test and the advantages of each alternative. Section 6.0 gives the recommendations and conclusions developed from the results of the testing. The recommendations presented are either improvements in the DMS-100 or future efforts for the OMNCS. The conclusions present the HEMP susceptibilities that were discovered in the testing.

# 2.0 RESULTS OVERVIEW

## 2.1 SUMMARY

The results show that the DMS-100 test article, without the optional Electromagnetic Interference (EMI) shielding, is inherently survivable against HEMP-induced hardware failures that affect call processing.2 When call processing was disabled, either operator action or system software was able to return call processing functions to 100% capability. Several modifications were performed to harden the system against call processing upsets. This section discusses the overview of the results acquired, modifications performed and lessons learned in the test program. This section describes the results obtained in the pretest susceptibility experiment, the Ottawa test, the REPS test and the AESOP test.

## 2.2 RESULTS

**Tables 2-1, 2-2,** and **2-3** summarize the test results and the interpreted data that should be used by the OMNCS for its survivability models. The model data differ from the raw data because, for the statistical model, the assumption is made that survivals in the higher bin indicate survivals in the lower bins. Therefore, for example, the sample size and survivals in the first bin are a sum of all three bins.

Without all the hardware and software modifications that NTI plans to include as part of all future switches, the DMS-100 switch is survivable to HEMP effects, but vulnerable to upset. **Table 2-1** includes the data to be used for the Network Connectivity Analysis Model (NCAM) statistical assessments where switch locations are assumed to be staffed and manual intervention is available. This table presents all data recorded during testing of the unshielded switch and includes data from both single and multiple pulses.

With all hardware and software modifications in place, the DMS-100 switch automatically recovered to 100 percent call processing capability within 20 minutes. Table 2-2 includes all data to be used for NCAM statistical assessments where switch locations are not assumed to be staffed and manual intervention is not available. This table includes all data for the switch in the final (modified) configuration. In this configuration, the switch was tested with only multiple pulses under AESOP at 60 kV/m. As a result of the modifications, call processing was unaffected or returned to 100 percent without manual intervention.

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[2] *Although no failures were observed during testing, there is a possibility of latent failures, which could only be found in a very thorough check of the switch.*

[3] *Single pulse events are those HEMP simulations after which the test article was returned to full call processing capability before the next simulation. Multiple pulse events were comprised of several pulses (shots) separated by several minutes, but with no attempt to ensure switch operability prior to each successive pulse.*

| Stress Level (kV/m) | Raw Data | | Model Data | |
|---|---|---|---|---|
| | Sample size | Failures | Sample size | Failures |
| 10-30 | 59 | 0 | 191 | 0 |
| 30-50 | 78 | 0 | 132 | 0 |
| 50-70 | 54 | 0 | 54 | 0 |

*Data Included: All data for unshielded configurations.

Table 2-1. DMS-100 Test Results: Manual Intervention Available

| Stress Level (kV/m) | Raw Data | | Model Data | |
|---|---|---|---|---|
| | Sample size | Failures | Sample size | Failures |
| 10-30 | 0 | 0 | 33 | 0 |
| 30-50 | 0 | 0 | 33 | 0 |
| 50-70 | 33 | 0 | 33 | 0 |

*Data Included: All data for unshielded configurations with all hardware and software modifications.

Table 2-2. DMS-100 Test Results: Manual Intervention Not Required

| Stress Level (kV/m) | Raw Data | | Model Data | |
|---|---|---|---|---|
| | Sample size | Upsets | Sample size | Upsets |
| 10-30 | 36 | 0 | 65 | 0 |
| 30-50 | 29 | 0 | 29 | 0 |
| 50-70 | 17 | 1 | 17 | 1 |

*Data Included: All data for the shielded configurations

Table 2-3 EMI Protected DMS-100 Test Results: Manual Intervention Not Required

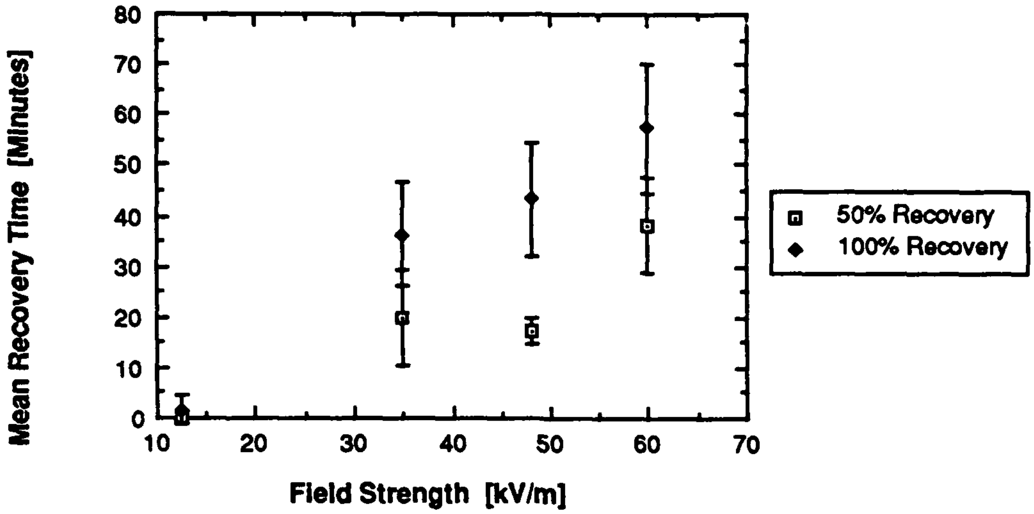



Figure 2-1. Summary of Mean Recovery Times Under HDL Simulators

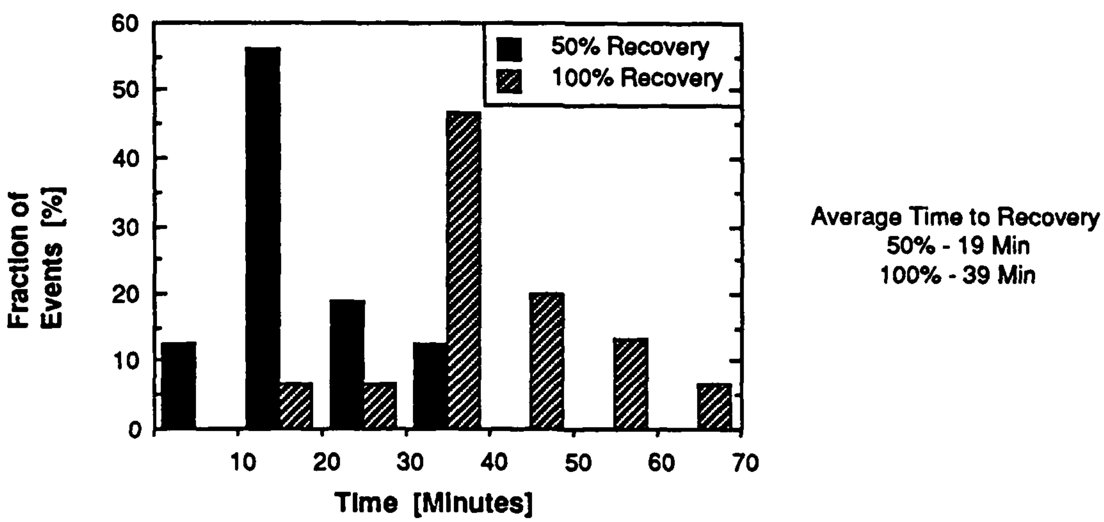



Figure 2-2. Recovery Time Distribution for Medium HEMP Stresses (30-50 kV/m)

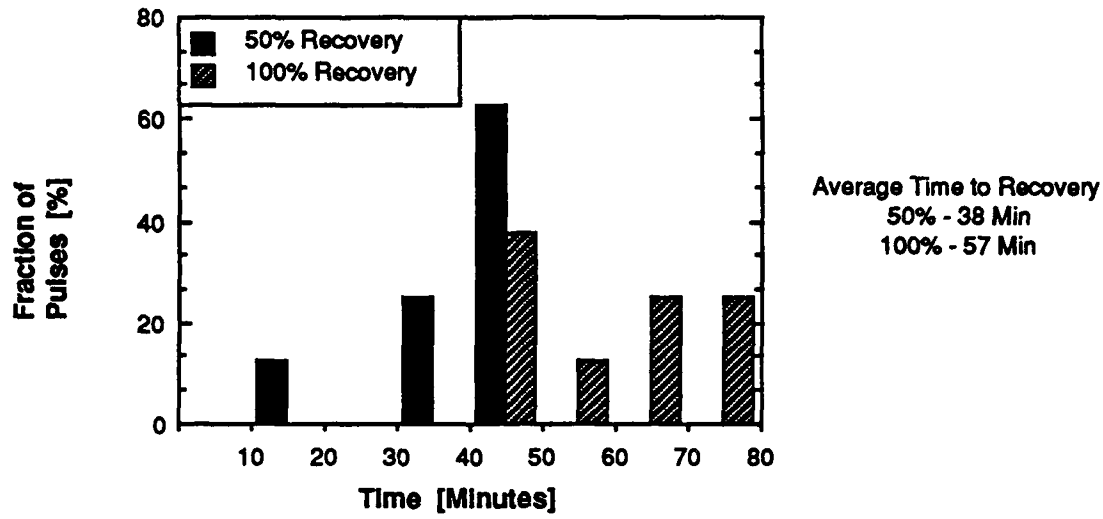



**Figure 2-3. Recovery Time Distribution for High HEMP Stresses (50-70 kV/m)**

With the EMI protection package in place, the DMS-100 was much less susceptible to HEMP, with only one interruption of call processing for 82 test events. **Table 2-3** includes the data to be used for NCAM statistical assessments for which interrupted call processing is of interest. The use of these data presumes that all switches have the EMI protection package installed, which also eliminates the need for manual intervention. With no EMI package installed, the switch suffered some degree of call processing interruption for virtually every pulse under REPS and AESOP.

The time required for the switch (without EMI protection) to recover after a simulated HEMP event is summarized in **Table 2-4** and **Figures 2-1, 2-2,** and **2-3.** The average times of call processing recovery (both 50% and 100% call processing recovery) for the various simulators are summarized in **Table 2-4. Figure 2-1** shows the average times of call processing recovery for the various field strengths produced by the simulators. Also indicated are the standard deviations of the recovery times. **Figures 2-2** and **2-3** present the distributions of recovery times for medium (10-30 kV/m) and high (50-70 kV/m) HEMP stress ranges, respectively.

## 2.3 PRETEST SUSCEPTIBILITY

A pretest susceptibility experiment was performed prior to the Ottawa test. A peripheral module, called the Remote Line Concentrating Module (RLCM), was subjected to both transient electromagnetic (EM) fields and injected current to determine any susceptible components in the module. The technology of the circuitry present in the RLCM's processor, memory and power converters was representative of that used in other parts of the system. Some of the conclusions drawn from the experiment are:

1. The EM field test showed that the RLCM's call processing functions, with the EMI shielding, is unaffected by the EM field of up to 110 kV/m peak level.

2. With the EMI shielding removed, the threshold of upsets involving loss of call processing was 35 kV/m.

3. The power and signal interfaces survive up to 9.17 Amps (p-p) of transient injected current on a conductor pair in a 16-pair cable.

The full details of the pretest susceptibility experiment are discussed in Appendix B.

## 2.4 OTTAWA TEST

The main objective for testing in Ottawa was to identify component vulnerabilities under a low-level (2.5 kV/m equivalent free field), fast risetime (1 ns), pulsed, radiated field. The test article was subjected to a total of 1016 pulse tests while the test article was undergoing cable cutover.

With the EMI shielding in place, the system was not affected by the radiated field. When the EMI shielding was removed, 2 call processing upsets occurred, but the system automatically recovered within 5 minutes. A logic upset (called Drop Sync) occasionally occurred (30%) but had no effect on call processing.

## 2.5 REPS TEST

The second phase of HEMP testing was conducted under the REPS at the WRF site. The REPS produced a peak level field of 10 kV/m, with risetime of 8 ns, at the test article. With the EMI shielding in place, the call processing capabilities were not affected by the fields.

When the EMI shielding was removed, the test article experienced call processing upset, which was caused by a power converter shutdown in the Line Trunk Controller (LTC) module. A filter capacitor was installed in the power converter that decreased the sensitivity to approximately 50%. Eventually, in the AESOP test (33 kV/m), a supervisory IC in the power converter unit was replaced with a hardware-compatible IC (manufactured by Unitrode), which deleted this upset problem.

## 2.6 AESOP TEST

The third phase of EMP testing was conducted under the AESOP at the WRF site. The AESOP produced field levels (8 ns risetime) of 33 kV/m, 48 kV/m, 60 kV/m and 69 kV/m at the test article. The 69 kV/m field level was generated only when the test article had full EMI shielding. With the full EMI shielding in place, the test article experienced only one call processing upset (at 60 kV/m) out of 46 pulse illuminations, caused by one of the Line Concentrating Modules (LCMs) exhibiting a log/memory corruption (called Sys B). This meant losing 50% of the call processing capability of the switch which was recovered in eight minutes.

With the EMI shielding removed, the test article experienced total call processing upset at every pulse (33, 48 & 60 kV/m), but all upsets were recoverable to 100% call processing through manual intervention. The upset problem was traced to two effects: power converter shutdown in the LCM modules and logic corruptions in the peripheral modules (e.g., LTC, LCM, TM8). Call processing was regained by manual reset operation and MAP-performed data download (from disk to PMs). The supervisory IC in the power converter units of each LCM was eventually replaced, and an "autoload" software package was installed. Then four sets of multiple pulses (4-16 pulses per set) were produced, and the test article automatically recovered to 100% call processing within 15 minutes, with the hardware and software modifications in place.

An experiment was performed that changed the configuration of the intra-office cables by looping the cables around the top and bottom of the switch frames, and an interesting result occurred. By this time, all the hardware and software modifications were in place. The LCM frames contained no EMI shields or filters, but the remainder of the switch contained the complete EMI package. Following the first set of multiple (10) pulses at 60 kV/m, call processing automatically recovered within 10 minutes. Other hardware effects occurred, but had no impact on the call processing function of the test article. These are power rectifier upsets and MAP keyboard failures, which are discussed in detail in Section 4.0. Although latent failures and reliability are not of interest to the OMNCS, the test article was operated for two weeks beyond the test period with no failures identified.

| CONFIGURATIONS | HEMP Simulator | Field kV/m | Time of Recovery (min) | | % of C.P. Upsets |
|---|---|---|---|---|---|
| | | | 50% C.P. | 100% C.P. | |
| Panels On & Filters On | REPS | 12 | | | 0 |
| Panels Off & Filters Off | REPS | 12 | | 4 | 44 |
| Panels On & Filters On | AESOP | 35 | | | 0 |
| Panels On & Filters On | AESOP | 48 | | | 0 |
| Panels On & Filters On | ASEOP | 60 | | 8.1 | 7 |
| Panels On & Filters On | AESOP | 69 | | | 0 |
| Panels Off & Filters On | AESOP | 35 | 13.6 | 20.3 | 100* |
| Panels Off & Filters Off | AESOP | 35 | 20 | 36.3 | 100* |
| Panels Off & Filters Off | AESOP | 48 | 17.3 | 43.2 | 100* |
| Panels Off & Filters Off | ASEOP | 60 | 38.2 | 57.4 | 100* |
| Panels On & Filters Off | AESOP | 35 | 4.6 | 13 | 100* |
| Panels On & Filters Off | AESOP | 60 | 19.5 | 20 | 100* |
| LCM Frames Unshielded | AESOP | 60 | 5 | 7.1 | 75 |
| LCM Frames Unshielded & LCM Cable Looped Around | AESOP | 60 | 6.7 | 11.8 | 100 |

**Table 2-4.**

**Average Time of Recovery from Single Shots at HDL Simulators.**

***Call Processing was completely interrupted.**

# 3.0 TEST ARTICLE, FACILITIES AND INSTRUMENTATIONS

## 3.1 SYSTEM DESCRIPTION OF TEST ARTICLE

The DMS-100 test article was configured to represent a typical DMS-100/200 switch installation in the network and was installed in a transportable trailer (size 40' by 8'). The test article was configured to include the major components that made up a DMS-100/200 system.

### 3.1.1 Physical Description

The physical layout of the test article inside the trailer is shown in **Figure 3–1**, and the front view of the switch frames are shown in **Figure 3–2**. The intra-office cables that ran between the MDF and the switch inside the trailer were laced along the top of the switch frames.

The trailer is constructed mostly of wood and fiberglass material except for the steel beams that forms the trailer frame, thus it provides almost no EMI shielding, which was confirmed by a shielding effectiveness test performed at the HDL/WRF. The test article contained an EMI protection package, which consists of shielding panels with conductive gaskets. There were four removable panels (2 on front, 2 on rear) on each frame. The EMI protection package also included line filters at the line penetrations on the frames. The line filters were applied at the 48 VDC power lines, subscriber lines, analog trunks and digital trunks. Only the line filters for the subscriber lines and trunks could be bypassed during the HEMP tests.

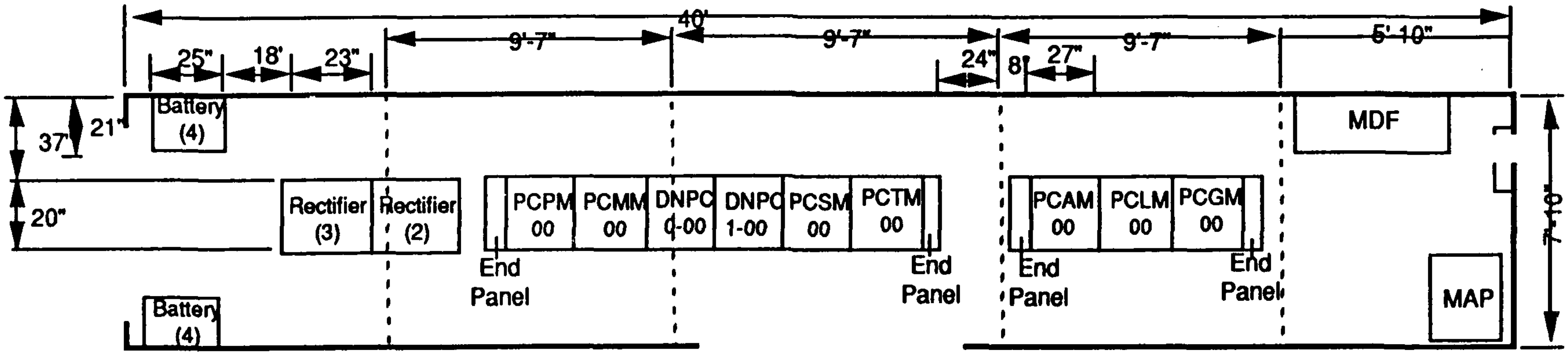
The test article was configured to provide interfaces to approximately 700 subscriber lines, 30 analog trunks and 96 digital trunks; however, the capacity of the frames was much greater. Switch call processing utilized only 96 subscriber lines, 24 analog trunks and 72 digital trunks during the test due to the limited capacity of the call simulator (load box).

Power was supplied to the test article as illustrated in **Figure 3-3**. The test facility provided the 120/208 VAC for the test article, which rectified the AC voltage to 48 VDC that supplied charge to the batteries. The batteries were designed to provide four hours of uniterruptible power to the test article in case of power outage.

### 3.1.2 Functional Description

The DMS-100/200 consists of four major subsystems which are illustrated in **Figure 3-4** and are described below:

1. Central Control Complex (CCC)
2. Maintenance and Administration
3. Network
4. Peripheral Modules (PM)




NOMENCLATURE

PCPM - Packaged Core Power Module
PCMM - Packaged Core Memory Module
DNPC - Dual Network Packaged Core
PCSM - Packaged Core Service Module
PCTM - Packaged Core Trunk Module
PCAM - Packaged Core Auxilliary Module
PCLM - Packaged Core Line Module
PCGM - Packaged Core General Module
MDF - Main Distribution Frmae
MAP - Maintenance And Administration Position

**Figure 3-1. Floor Plan Of Test Article**

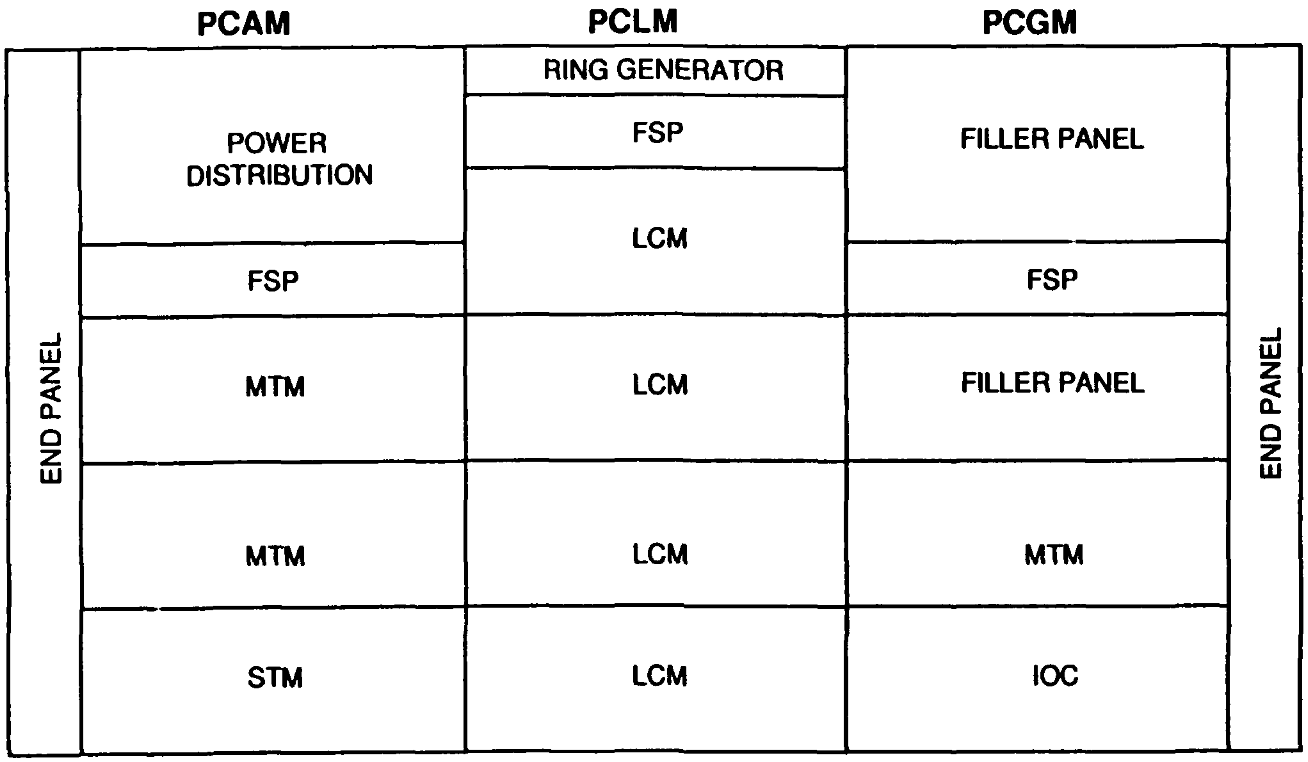
| | PCPM | PCMM | DNPC | DNPC | PCSM | PCTM | |
|---|---|---|---|---|---|---|---|
| END PANEL | POWER DISTRIBUTION | TAPE DRIVE | NETWORK (PLANE 0) | NETWORK (PLANE 1) | MTM | LTC | END PANEL |
| | | | NETWORK (PLANE 0) | NETWORK (PLANE 1) | TM 8 | LTC | |
| | FSP | FSP | FSP | FSP | FSP | FSP | |
| | MTM | DS | CMC/IOC | CMC/IOC | TM 8 | LTC | |
| | MTM | DS | CPU | CPU | STM | LTC | |
| | DDU | DDU | COOLING UNIT | COOLING UNIT | STM | COOLING UNIT | |

NOMENCLATURE

FSP - Frame Supervisory Panel
MTM - Maintenance Trunk Module
DDU - Disk Drive Unit
DS - Data Store
CMC - Central Message Controller

IOC - Input/Output Controller
CPU - Central Processing Unit
TM8 - Trunk Module Type
STM - Service Trunk Module
LTC - Line Trunk Controller

**Figure 3-2. Switch Frame Configuration (Front View)**




NOMENCLATURE

FSP - Frame Supervisory Panel
MTM - Maintenance Trunk Module
STM - Service Trunk Module
CMC - Service Trunk Module
IOC - Input/Output Controller
LCM - Line Concentrating Module

**Figure 3-2 (Cont.). Switch Frame Configuration (Front View)**

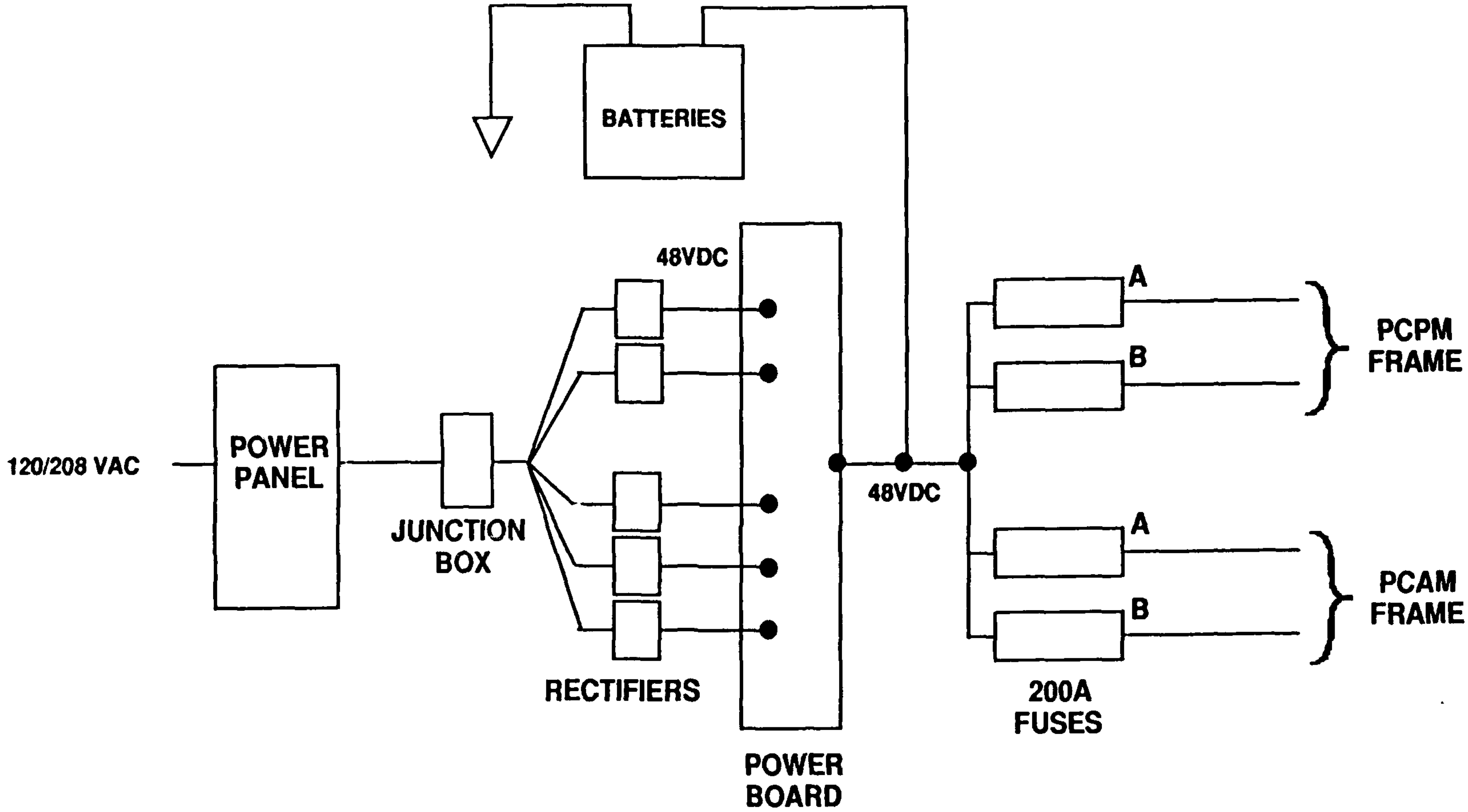
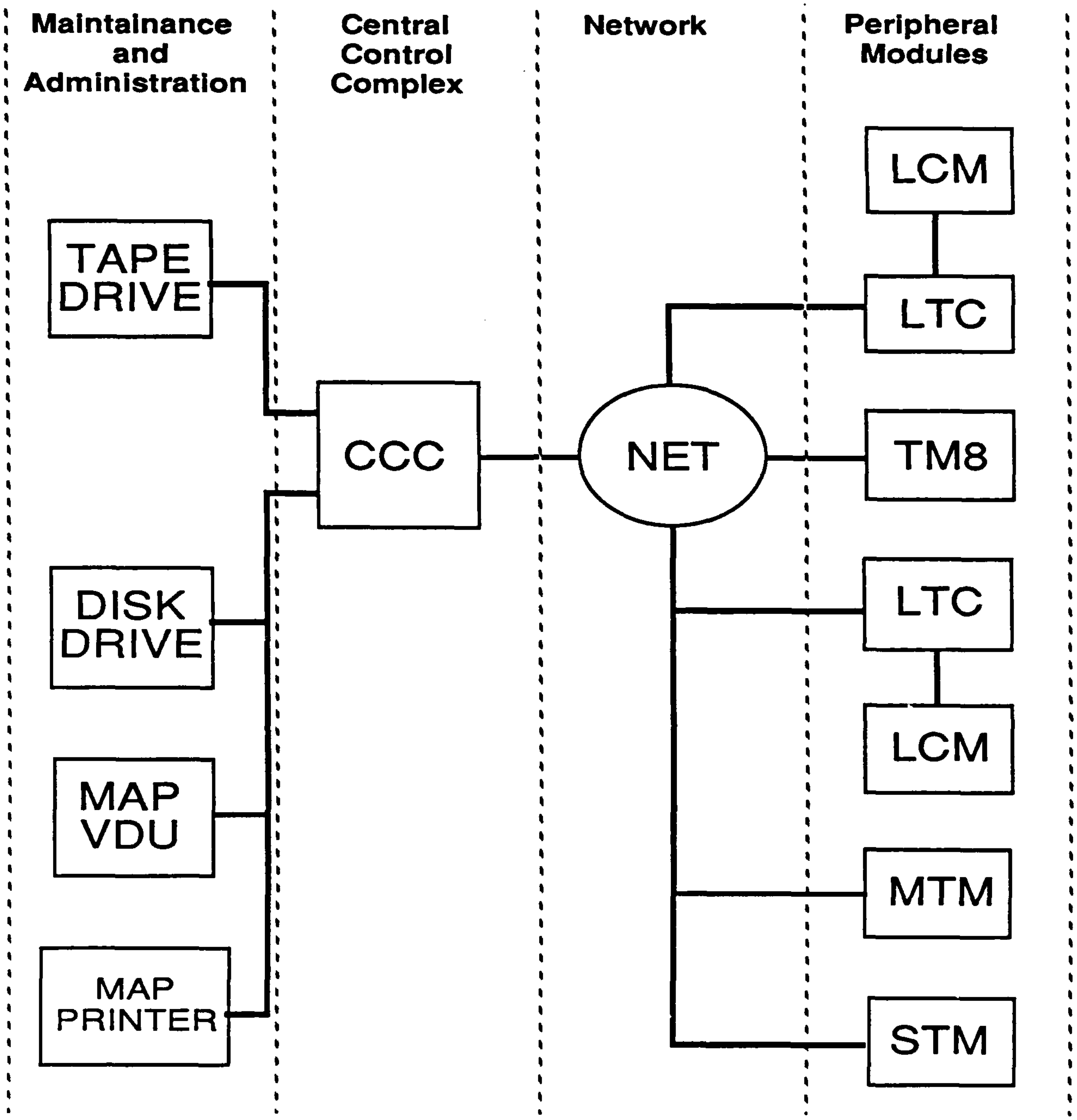



Figure 3-3. Power Subsystem Configuration




NOMENCLATURE

LCM - Line Concentrating Module
LTC - Line Trunk Controller
TM8 - Trunk Module (8 Wires)
MTM - Maintenance Trunk Module
NET - Network
STM - Service Trunk Module
MAP - Maintenance And Administration Position
CCC - Central Control Complex

**Figure 3-4. Major DMS-100 Component Interconnections**

### 3.1.2.1 Central Control Complex (CCC)

The CCC, illustrated in **Figure 3-5**, is a duplicated group of four modules that act together to evaluate incoming messages, format the proper response, and issue instructions to subsidiary units. The four modules comprising the CCC and their functions are:

**CENTRAL MESSAGE CONTROLLER (CMC)** - The CMC controls the message flow between the network, maintenance and administration areas and the CPU. Redundant message links are utilized for reliability.

**CENTRAL PROCESSOR UNIT (CPU)** - The CPU, which is located in the Central Processor and Memory (CPM) shelf, has access to each CMC and its dedicated memory modules, where stored programs and office data are located. The CPU contains the logic required to control all operations of the DMS-100.

**PROGRAM STORE (PS)** - The PS module, located in the CPM shelf, is associated exclusively with one CPU and contains the program instructions required by the CPU for call processing, maintenance, and administration tasks.

**DATA STORE (DS)** - The DS module, located in a DS shelf, is associated exclusively with one CPU and contains transient information on a per-call basis, as well as customer data and office parameters.

The CPU, which controls all operations of the DMS-100, has an interface to all of the modules comprising the CCC. The bus interfaces and their main functions are:

**DATA PORT BUS**

- Interfaces each CPU to its dedicated Data Store memory
- Interfaces CPU to both CMCs
- (The data port bus is a parallel bus)

**PROGRAM PORT BUS**

- Interfaces each CPU to its dedicated program store memory
- (The program port bus is a parallel bus)

**MATE/MAINTENANCE EXCHANGE BUS (MEB)**

- Interconnects the two CPUs
- Provides an exchange of information between the CPUs in order to perform synchronization, matching, and maintenance functions

### 3.1.2.2 Maintenance and Administration

The Maintenance and Administration components consist of the Input/Output Controller (IOC) and the I/O terminals, such as the MAP (VDUs and printers), Magnetic Tape Drive (MTD), and the Disk Drive Unit (DDU). The test article had a maximum of 3 VDUs, 2 printers, 1 MTD, and 2 DDUs in the system.

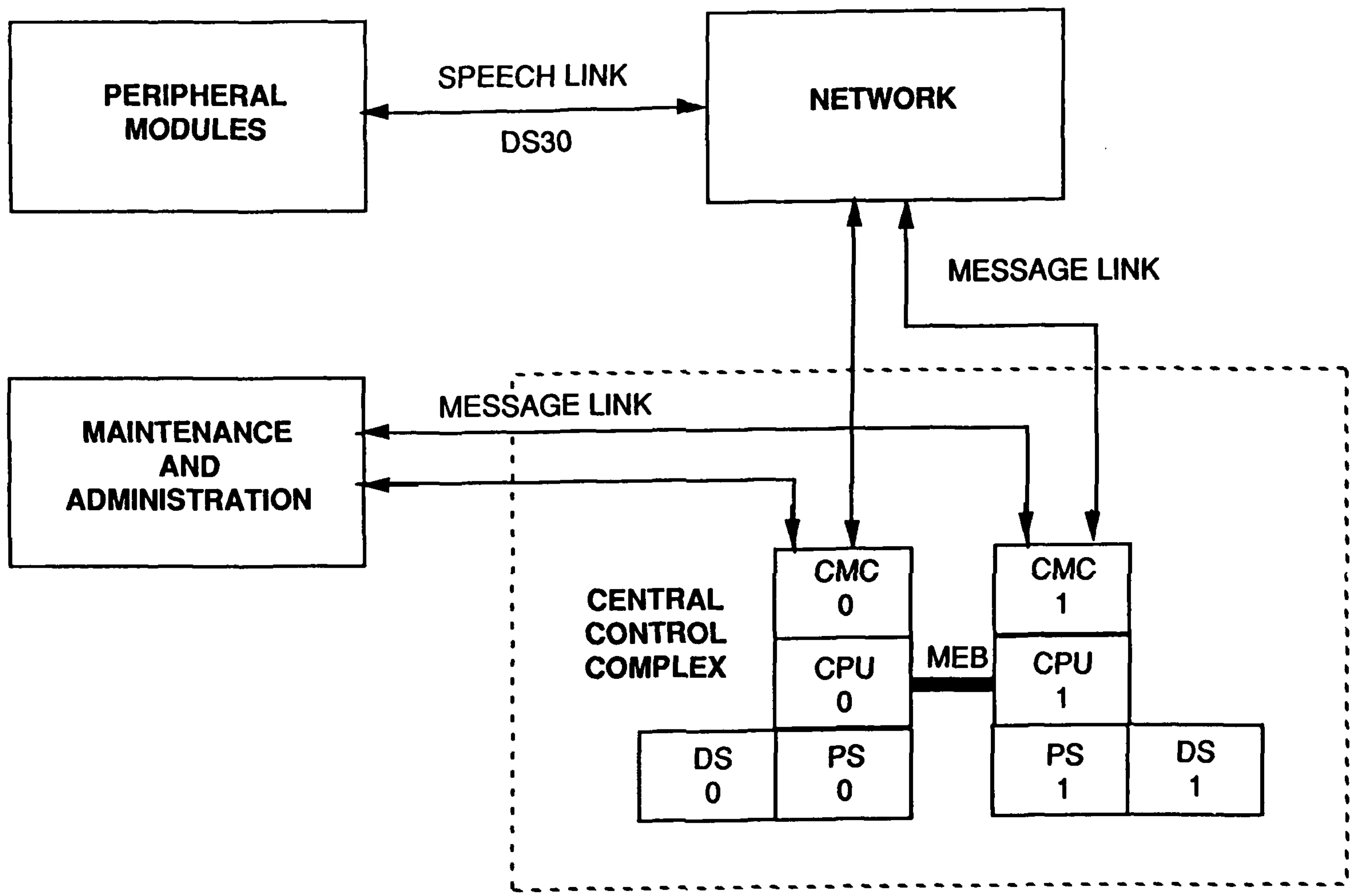



Figure 3-5. Central Control Complex Modules

### 3.1.2.3 Network

The main function of the network is the electronic switching and routing of speech paths between users. Electronic switching is accomplished through a four-stage, time-switching technique employed in the Network Module (NM). For each Network Module in the network, up to 64 DS-30 links can be time switched. Since DS-30 carries 30 voice plus 2 signaling channels, each NM can time-switch up to 1,920 (30 * 64) voice channels.

The NM subsystem, which is duplicated for reliability purposes, was installed in the DNPC frames of the test article and provided more than enough capacity as it interfaces with the peripheral modules and the CPU.

### 3.1.2.4 Peripheral Module (PM)

The PM allowed the DMS-100 system to interface with the outside world or external lines, such as subscriber lines, analog trunks, and digital trunks. Three types of PMs are configured into the test article. They are the Trunk Modules, the Line Concentrating Module, and the Line Trunk Controller which are described below. Other types of PMs in the DMS-100 family are very similar to those in the test article.

**TRUNK MODULE (TM)** - Each TM accepts 30 analog trunk circuits and performs 32-channel, time-division Pulse Code Modulation (PCM) of speech and control signals for conversion to DS-30 links. Demodulation is performed by the TM to convert from DS-30 to analog signals. Dual DS-30 links are used by the redundant NM pair, but the TM itself is not redundant.

The TM8-type units were selected for the test. They are contained within the PCSM frame and are composed of peripheral processor cards and trunk circuit cards.

Another version of the TM contained in the test article was the Maintenance Trunk Module (MTM). The MTM accommodates service circuits, such as DTM receivers, announcement trunks, and test circuits. Each MTM has the capacity for interfacing 24 service circuits.

**LINE CONCENTRATING MODULE (LCM)** - The LCM is designed to interface with telephones, attendant consoles, low-speed and high-speed data units, RS-422 compatible devices, and personal computers. Each LCM occupies two shelves and each shelf contains a power supply, controllers and up to 320 line interfaces. The power supply and controllers in each shelf provides "hot" backup to the other shelf in an LCM for greater reliability. The LCM interfaces with the LTC through DS-30A links. One frame (PLCM) containing 2 LCMs was provided with the test article.

**LINE TRUNK CONTROLLER (LTC)** - The LTC provides interfaces to digital trunks (DS1 and DS-30A). Up to 20 DS1 trunks (480 channels) or up to 16 DS-30 links (480 channels) can interface with each LTC. The LTC also contains dual controllers and dual power supplies for reliability purposes. Two LTCs were provided in the test article.

## 3.2 TEST FACILITIES

The following discussions describe the EMP simulation sources that were used to induce transients into the test article.

### 3.2.1 EMP Simulation Sources (OTTAWA TEST)

The simulator that was used for the Ottawa test was the HDL-built, transportable 250 kV pulser. The pulser and the antenna cables were transported to the Ottawa test site where they were installed onto three 70-foot poles as shown in **Figure 3-6.**

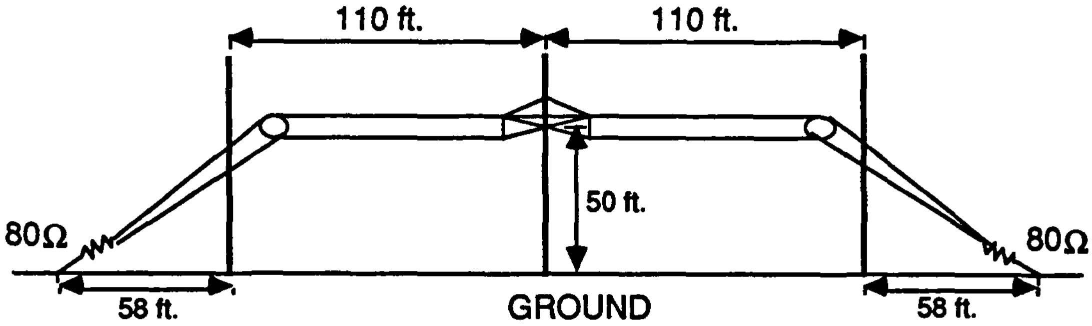



**Figure 3-6. EMP Simulator At Ottawa**

The 250 kV pulser consisted of a 250 kV pulse generator and a horizontal dipole antenna extending horizontally from the pulser for 110 feet and then terminated to ground. The pulser provided an equivalent radiated free field of 2.5 kV/m at 25 meters (centerline distance) from the pulser. The output pulse is an exponential damped wave with less then a 20% undershoot. The first crossover occurs between 7 and 200 ns, depending on the risetime. The nominal risetime can be set between 0.7 and 2.0 ns. The pulser can be fired as frequently as once per 20 seconds. Coverage and angle of incidence will depend upon the test setup. The majority of the tests were conducted with the pulser antenna parallel to the longest cables connected to the equipment. **Figure 3-7** shows one electric field waveform, which includes the ground interactive field, measured at 25 meters.

### 3.2.2 EMP Simulation Sources (WOODBRIDGE TEST)

The test article was illuminated with simulated EMP at Woodbridge using the Repetitive EMP Simulator (REPS) and the Army EMP Simulator Operations Pulser (AESOP).

The REPS is an intermediate-sized simulator with a 1 MV pulser that drives a 300-meter long, 150-Ohm horizontal dipole antenna. The pulser and antenna are supported by wooden poles and have a maximum height of 15 meters. REPS produces a horizontally polarized electric fields with a risetime of 8.0 ns, and a maximum equivalent free field amplitude of 12 kV/m at 25 meters.

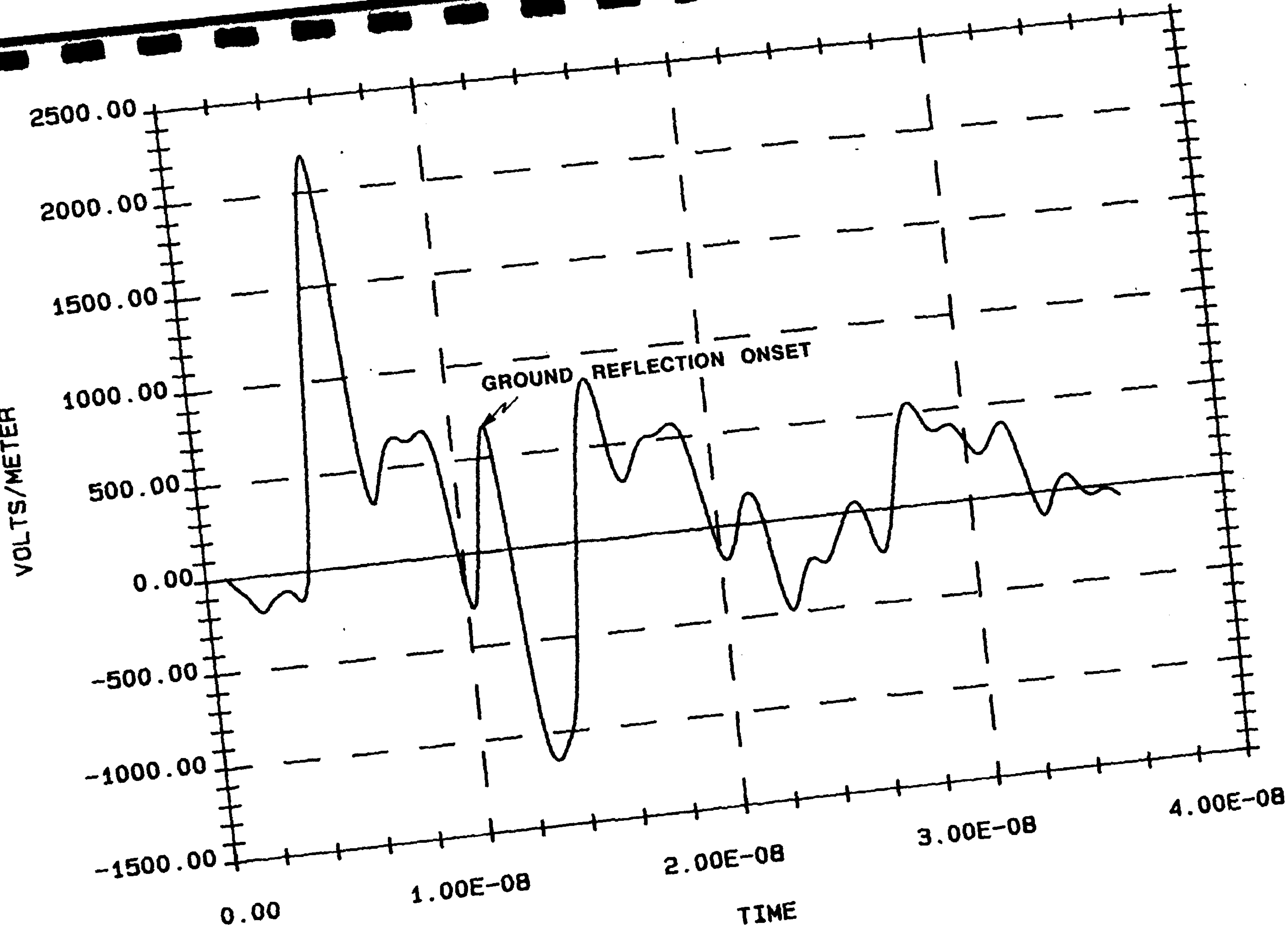



Figure 3-7. Field Measurement at Ottawa

AESOP is a fixed-site, large-area, threat-level EMP simulator. The 7 MV pulse generator (two synchronized 35 stage Marx generators and 16 3.5-MV peaking capacitors) drives a 300-meter, 120-ohm dipole antenna. The pulser and antenna are supported by wooden poles and have a height of 20 meters. AESOP produces a horizontally polarized electric field with a rise time of 8 ns and an equivalent free field amplitude of up to 70 kV/m, 30 meters away. The AESOP field levels were adjusted to produce 33 kV/m, 48 kV/m, 60 kV/m and 69 kV/m nominal at 30 meters during testing.

## 3.3 TEST INSTRUMENTATION

The two types of measurements performed in the test program were transient signal and call processing measurements. Transient signals were measured with wide bandwidth probes, sensors, analog/digital scopes and associated devices. Call processing measurements were recorded with the load box and the MAP station, which are discussed below. Great effort was expended to isolate these equipment from the radiated field from the HEMP simulators through the use of shielding, fiber optic links and signal filtering.

### 3.3.1 Transient Measurement Devices

Wide bandwidth instruments were required to capture and record the transient radiated fields and induced signals. **Figure 3-8** illustrates the configurations of the three types of equipment used in the test program. The Tektronix 2467 is an analog oscilloscope with a bandwidth of 350 MHz. It requires a Tektronix camera with fast-writing Polaroid film to record the transient signals. The Hewlett Packard 54111D and Tektronic 7912AD were digital oscilloscopes that record measured signals in internal memory. They are program controlled through the GPIB interface. **Table 3-1** lists the various instruments and devices used in the test program and where they were utilized.

### 3.3.2 Load Box and MAP Station

The load box and the MAP station were used primarily to diagnose and record the upsets experienced by the test article after pulse illuminations. The load box provided simulated call traffic through the switch through 48 originating lines and 48 terminating lines. **Figure 3-9** illustrates the use of the load box as it distributes call traffic through the switch components. The load box counted the number of attempted calls and the number of unsuccessful calls for a period of time. The load box also determined the type of problem that caused the unsuccessful attempts. These problems were diagnosed as either busy tone, dial tone, fast busy, path verification tone (PVT), quiet ringing, or ringback (Reference 4). The box was programmed to generate 200 calls/minute.

The number of lines from the load box was evenly distributed through all the LCM units in the switch. All originating lines were connected to LCM-0 and all terminating lines were connected to the LCM-1. Each link between incoming and

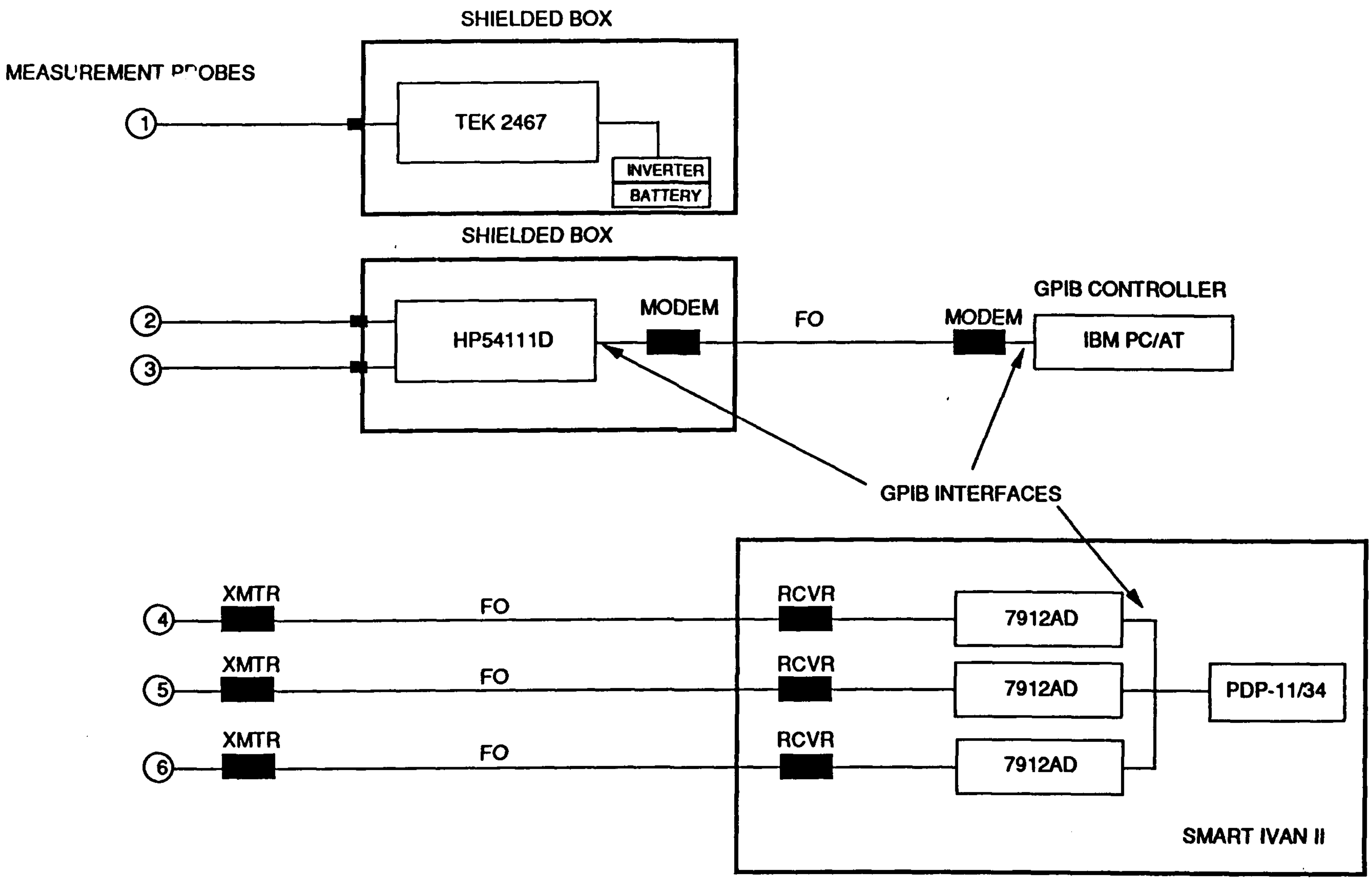



**Figure 3-8. Translent Measurement Configuration**

**Table 3-1. Instruments And Devices Used In Test Program**

**DATA RECORDERS**

| Model | Facility |
|---|---|
| Tektronix 2467 | O |
| Hewlett Packard 54111D | R |
| Tektronix 7912 (SMART IVAN II) | R,A |

**FIELD SENSORS**

| Model | Facility |
|---|---|
| In-House Monopole | O |
| H106 | O |
| MGL-7 | O |
| MGL-2 | O |
| MDE | O |

**CURRENT PROBES**

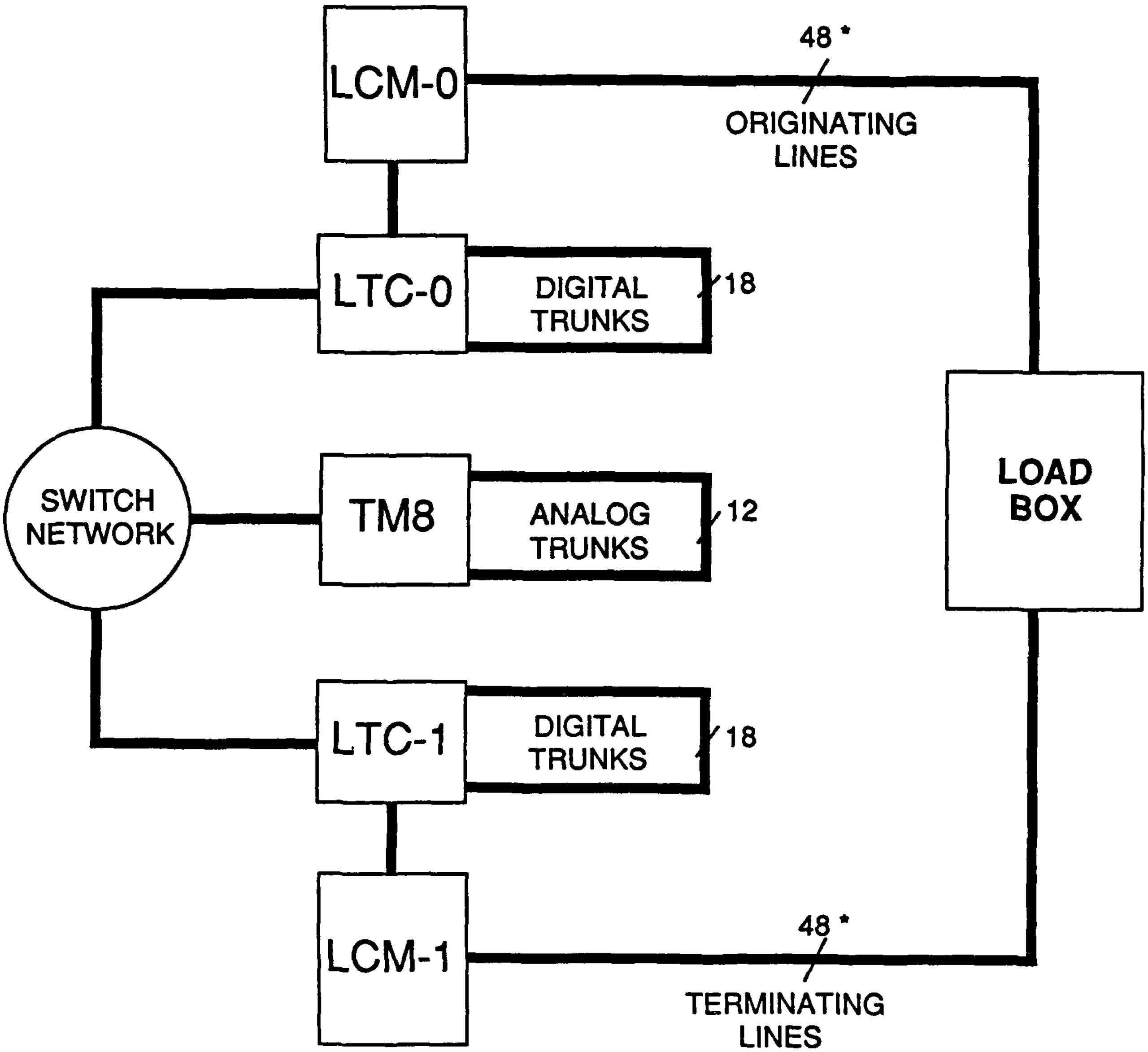
| Model | Window(in.) | $Z_t$(ohms) | Freq. Range | Facility |
|---|---|---|---|---|
| 94456-4 | 4.0 | 0.06 | 10kHz-100MHz | O,A |
| 91550-3 | 1.25 | 0.03 | 3kHz-110MHz | O,R,A |
| 91550-2 | 1.25 | 1.0 | 40kHz-110MHz | O,R,A |
| 93686-3 | 2.625 | 2.0 | 70kHz-120MHz | O |
| 93686-4M | 2.625 | 0.005 | 70kHz-120MHz | A |
| COP-5 | 0.181 | 5.0 | 50kHz-150MHz | R,A |

Notes:

O - Ottawa

R - REPS

A - AESOP




LEGENDS:

LCM - Line Concentrating Module (Subscriber Line Interface)

LTC - Line Trunk Controller (Digital Trunk Interface)

TM - Trunk Module (Analog Trunk Interface)

* Only 36 out of the 48 links were operational in Ottawa.

**Figure 3-9. Load Box Traffic Link Distribution**

outgoing lines were routed through either a digital or analog trunk, thus all call traffic from the load box was routed through the LTC or TM8 modules. This distribution of links enabled the load box traffic to utilize all of the different types of switch peripheral modules.

The MAP station was used to analyze in greater detail the operational status of the switch through the use of the system's diagnostic program. The MAP was made up of DEC VT-220 video terminals and DEC LA-120 printers. These I/O devices were connected to the I/O ports of the DMS-100's CCC module through serial data links. The diagnostic information was projected on the VDU screen and the printer hardcopy.

# 4.0 SIMULATED HEMP FIELD TEST

## 4.1 INTRODUCTION

The DMS-100 HEMP test was performed by illuminating the test article with fast risetime (1 to 8 ns), high level (2.5 to 70 kV/m) transient electromagnetic fields. The test article was initially tested at Ottawa with HDL's 250 kV pulser beginning on 15 October 1987 and ending on 14 November 1987. The equivalent free-field level generated at Ottawa was 2.5 kV/m nominal at a centerline distance of 25 meters. The test article was then transported to the Woodbridge Research Facility in Woodbridge, Virginia where it was tested at the REPS (10 kV/m) and the AESOP (33 - 70 kV/m) facilities. The REPS test began on 11 December 1987 and ended on 22 January 1988, and the AESOP test began on 11 February 1988 and ended on 17 March 1988. The various field levels were selected in accordance with the NCS requirements to gather switch response data at specific ranges. These ranges were 10-30 kV/m, 30-50 kV/m and 50-70 kV/m.

## 4.2 TEST ARTICLE CONFIGURATIONS

Various physical configurations of the test article were tested at each field level. The configuration defines the degree of EMI shielding and protection that was installed during any test. **Table 4-1** shows the total number of pulse illuminations produced for each configuration of the test article. The numbers included both single and multiple pulses. The following describes the configurations:

Panels On, Filters On. The test article was completely shielded with EMI frame panels (front and back) and all power, subscriber, and trunk lines were filtered.

Panels On, Filters Off. The filters for the subscriber and trunk lines were removed and all shielding panels were installed.

Panels Off, Filters On. All front and rear shielding panels were removed, and all signal and power lines were filtered.

Panels Off, Filters Off. All front and rear panels were removed, and all subscriber and trunk lines were unfiltered.

Other Configurations. Two other configurations are shown in the chart. One configuration consisted of removing the panels and filters from the LCM frame, whereas all other panels and filters were left in place. The other configuration is similar to the previous one, with the exception that the LCM cable was looped around inside the switch trailer to optimize coupling into the LCMs.

Grounding Configurations. The grounding configuration of the test article for the Ottawa and REPS tests, illustrated in **Figure 4-1**, is different from that used during the AESOP testing, illustrated in **Figure 4-2**. The change in grounding configurations alimented the ground loop established through the two ground rods. The effect of this change on the induced transients is discussed in Volume III.

| CONFIGURATIONS | Ottawa 2.5 kV/m | REPS 10 kV/m | AESOP 33 kV/m | AESOP 48 kV/m | AESOP 60 kV/m | AESOP 69 kV/m | Total |
|---|---|---|---|---|---|---|---|
| Panels On Filters On | 824 | 36 | 14 | 15 | 14 | 3 | 906 |
| Panels On Filters Off | — | — | 5 | — | 7 | — | 12 |
| Panels Off Filters On | 83 | 24 | 17 | — | — | — | 124 |
| Panels Off Filters Off | 109 | 59 | 30 | 48 | 54 | — | 300 |
| LCM Frames Unshielded | — | — | — | — | 4 | — | 4 |
| LCM Frames Unshielded LCM Cable Looped Around | — | — | — | — | 26 | — | 26 |
| Total | 1016 | 119 | 66 | 63 | 105 | 3 | 1372 |

**Table 4-1. Summary of Number of Test Events (Pulses) for Each Configuration**

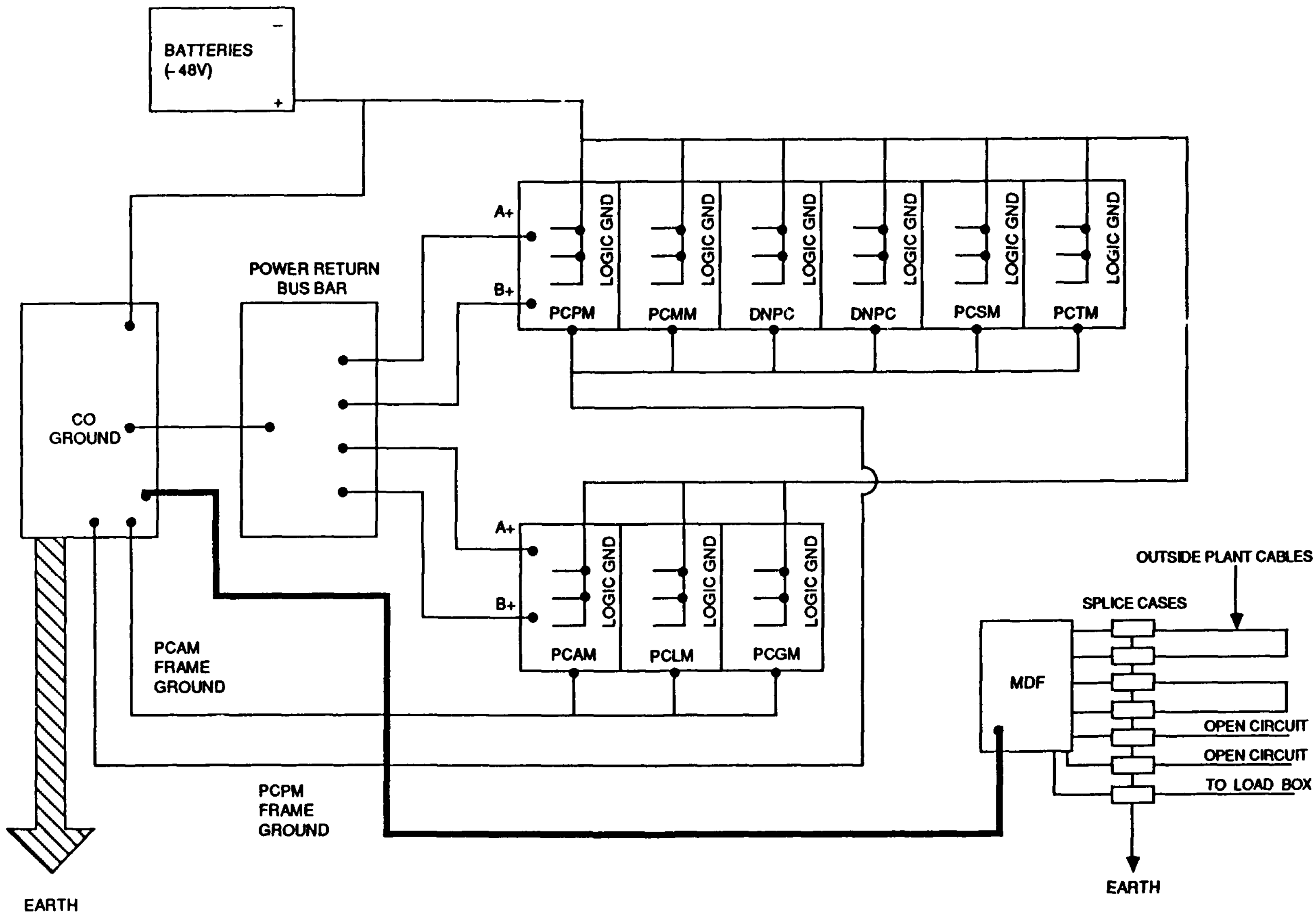



**Figure 4-1. Grounding Configuration for Ottawa and REPS Tests**

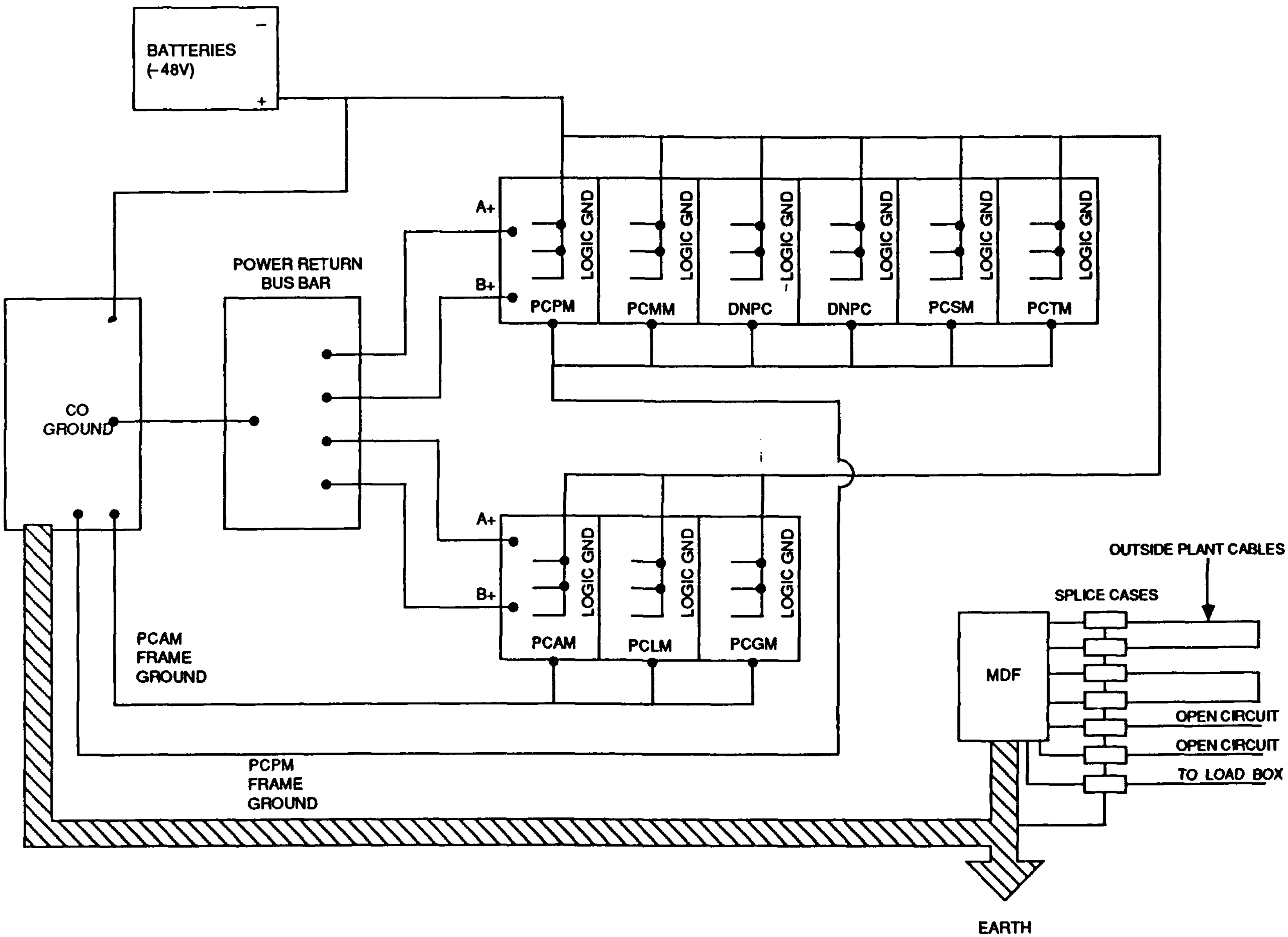



Figure 4-2. Grounding Configuration for AESOP Test

## 4.3 TEST PROCEDURES

This section describes the physical test setup at the three test sites and the experimental procedures that were performed.

### 4.3.1 Test Setup

**Figure 4-3** shows the test setup for the Ottawa test. The outside plant cables were composed of six cables (100 pairs each) that were used as subscriber loops, analog trunks and digital trunks. These cables were stretched out to approximately 200 feet at an elevation of approximately 8 feet and oriented parallel to the pulser antenna. The load box cable was laid on the ground and was oriented for minimum field coupling (perpendicular to the antenna). The outside plant cables and the load box cable entered the switch trailer and were distributed to the various peripheral modules in the switch. The 100-foot intra-office cables (inside the trailer), which ran between the MDF and the switch, were folded and harnessed on top of the switch frames.

The MAP station was positioned inside the switch trailer. It consisted of one DEC VT-220 video terminal and one DEC LA-120 printer. The LA-120 provided hardcopy of the diagnostic information generated by the switch. The load box and a DEC LA-100 printer were remotely located in the utility building. The LA-100 provided hardcopy of the call statistics information generated by the load box.

The test article was undergoing cable installation during the testing at Ottawa. The main distribution frame (MDF) wiring and the load box wiring were being installed and were not fully completed until the last week of the test. This did not seem to impact the operational upset results but may have affected the measured cable current due to the changes in the terminations (connected or unconnected). Unfortunately, there is a lack of common test points to compare results for the switch before and after the wiring changes.

At the REPS test facility the switch trailer was positioned 25 meters (centerline distance) from the pulser. An office trailer was acquired for the test and was positioned about 150 feet behind the switch trailer. The office trailer contained the load box, the MAP station and the computer that provided program control to the digital oscilloscope. The oscilloscope was a Hewlett Packard (HP) 54111D, which was placed inside a shielded box positioned near the switch trailer. The SMART IVAN II trailer contained transient digitizers providing three additional data channels. **Figure 4-4** shows the test setup at the REPS test facility. The following describes the various parts of the configuration setup at the REPS facility.

Power. AC power (120/208V, 3Ø) was supplied to the test article. In the trailer, the AC voltage was converted to 48 VDC by the use of rectifiers and regulators. This in turn was used to supply charge to the batteries inside the trailer and supply power to the switch. AC power outlets were installed inside the switch trailer for other equipment use.

Outside Plant Cables. These cables were suspended 8 feet above the ground and extended to approximately 500 feet parallel to the pulser antenna.

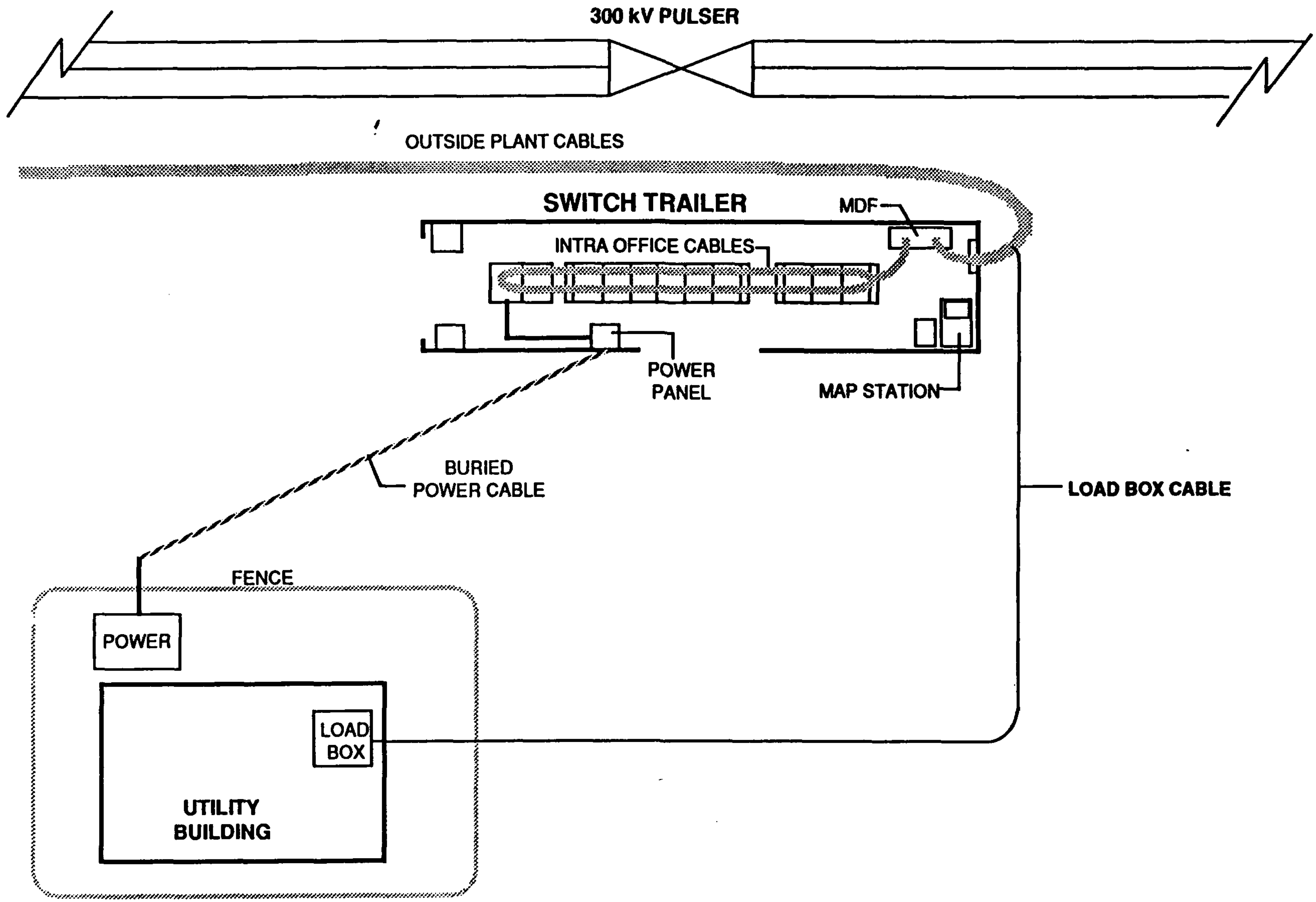



Figure 4-3. Test Setup (Ottawa)

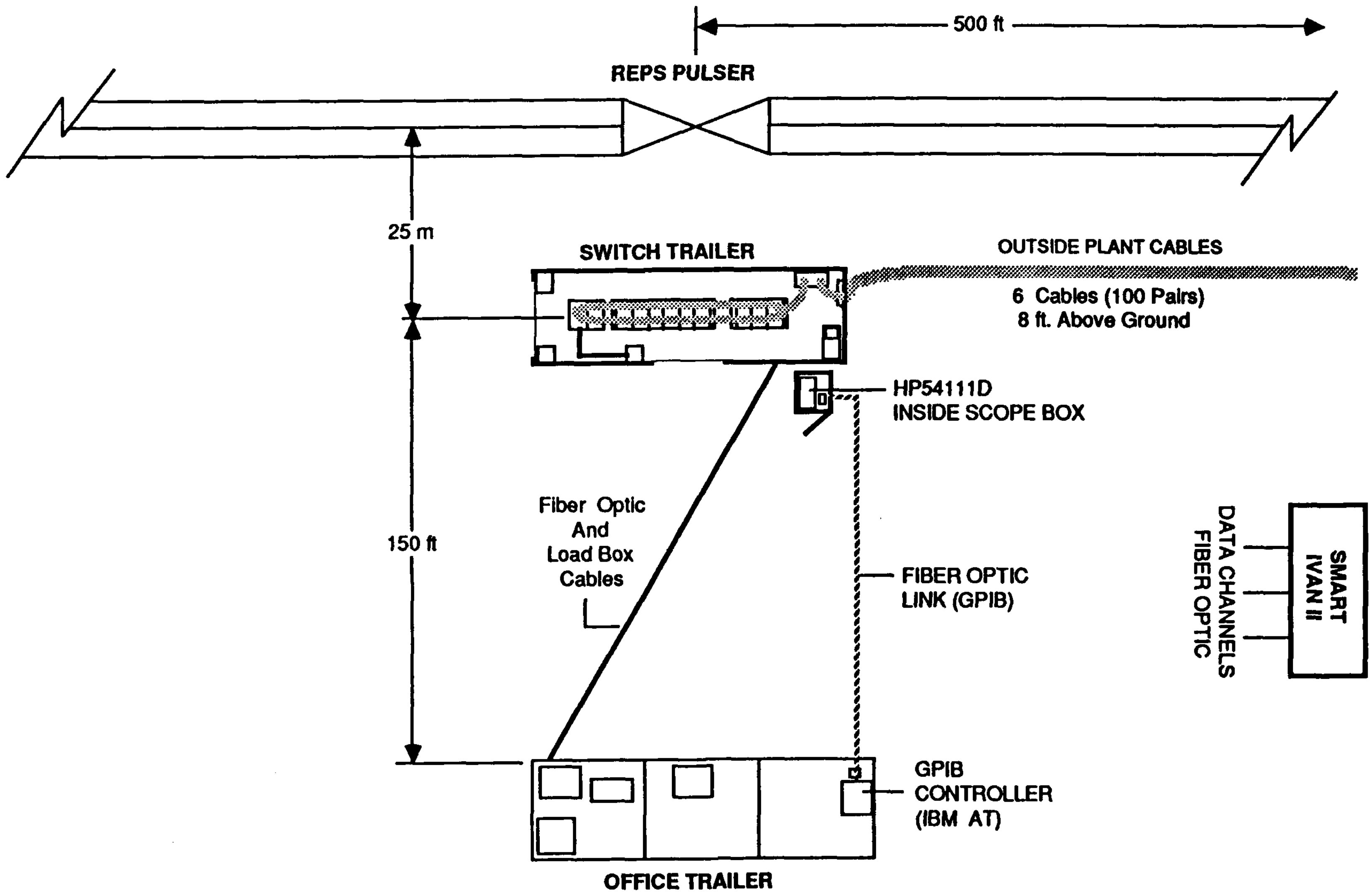



Figure 4-4. Test Setup (REPS)

MAP Station. A MAP station was positioned remotely in the office trailer, and another MAP station was positioned inside the switch trailer. Fiber optic RS-232C links were used between the remote MAP and the switch for EMP field isolation. The remote MAP station was comprised of two VT-220 video terminals and one LA-120 printer, and the MAP station inside the switch trailer consisted of one VT-220 and one LA-120.

Load Box. The load box was also positioned remotely in the office trailer. A 100-pair cable carried the simulated traffic between the load box and the switch. A LA-100 printer was connected to the load box for call statistics printout.

The test setup at the AESOP facility was similar to that of the REPS test. **Figure 4-5** illustrates the test setup. The office trailer was further behind the switch trailer due to the higher field levels and the equipment inside the office trailer were unprotected. The SMART IVAN II was the primary instrumentation for measuring and recording transient field and current waveforms.

### 4.3.2 Experimental Procedures

Illumination testing began before the test article was fully operational at Ottawa. It was three days before the end of the Ottawa test when the MDF was completely wired. Pulse illumination testing was initially performed on the test article configured with full EMI shielding installed. Measurements were collected and recorded on field mapping, coupled cable currents and switch responses. The frame panels were then removed, and similar measurements were collected. The filters for the subscriber lines and trunks were then bypassed, and the switch was illuminated again.

Pulse illumination testing at REPS and AESOP was initially performed on the test article with the EMI shielding installed. The testing then continued, as in the Ottawa testing, first removing the panels, then removing both the panels and the filters.

At the AESOP facility, the field level was varied from 33 kV/m to 69 kV/m. The field levels were adjusted at three specific levels at a distance of 30 meters: 33 kV/m, 48 kV/m and 60 kV/m (nominal). The field level was also elevated to 69 kV/m for the fully-shielded test article.

Prior to each pulse event (single or multiple) at all three test sites, the switch's call processing function was operational, and the oscilloscope and digitizers were armed (in single trigger mode) to capture transient waveform data. The MAP video terminal indicated that all units of the switch are operational. After a pulse event, the following typically occurred:

- The load box operator began printing call processing statistics per time interval (2 minutes typically) until the system regained 100% call processing. The information on the load box report consisted of the number of attempted calls and the number of failed attempts. The load box information also showed the cause of the failed attempt.

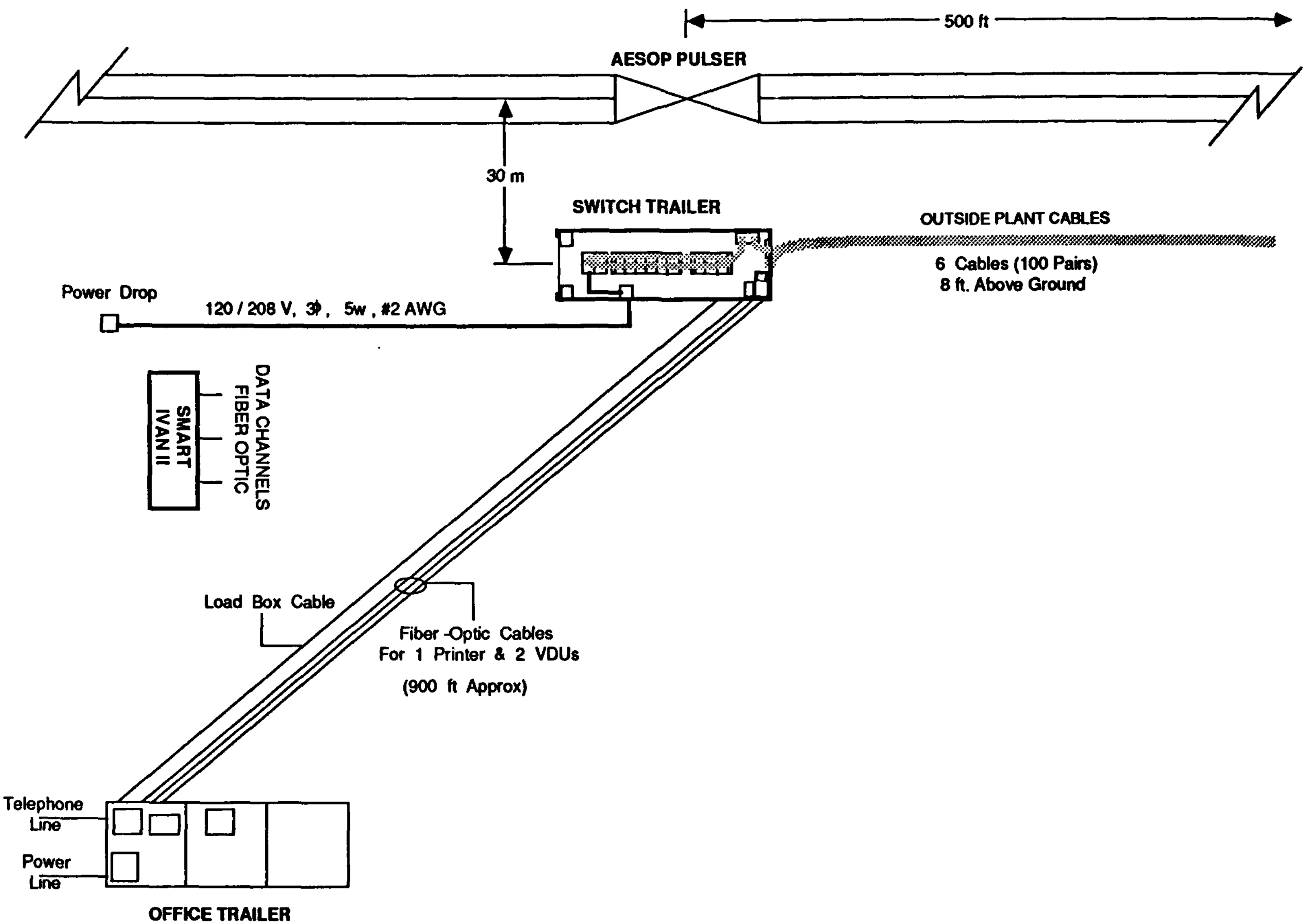



Figure 4-5. Test Setup (AESOP)

- The MAP operator examined the video screen for diagnostic responses. Diagnostic information would appear on the screen and was printed out when the switch detected subsystem upsets or failures. The information could be used by the MAP operator to isolate the problem down to the circuit card unit. It was discovered that the fault tolerant software of the switch provided automatic operational recovery for most upset problems. However if the upset had been caused by power converter shutdown or memory corruption, then manual intervention such as power reset and downloading from disk or tape would be required.
- Transient waveform data were acquired by the digitizers and were logged onto disk files with the proper file name and header information for convenient referencing.

## 4.4 OPERATIONAL TEST RESULTS

The results show that the test article suffered no permanent call processing failure at all field level tests. The results also show that, except for one isolated pulse at AESOP (60 kV/m), the fully-shielded test article suffered no call processing upsets. The following sections describe the results at the three test sites. Detailed results for the testing, by shot number, are included in Appendix C.

### 4.4.1 Ottawa Test Results

The Ottawa test results are summarized in this subsection. A detailed report is contained in Reference 2. The DMS-100 switch was subjected to 1016 pulses under the RPG simulator. With the EMI package, the switch did not show any operational upsets. When the EMI package (frame panels and signal filters) was removed, the central processors dropped SYNC occasionally which did not affect call processing capability of the switch. The switch lost SYNC after 24% of the pulses. Only two pulses (1%) caused a Warm or Cold Restart. **Figure 4-6** illustrates the system restart scenario during the pulse testing. System restart occurred when both redundant CPU experienced logic corruption which caused the system software to transfer "clean" data to both CPUs.

### 4.4.2 REPS Test Results

The DMS-100 switch was subjected to 119 pulses at the REPS. With the EMI package (frame panels and signal filters) in place, neither preset calls nor call processing capabilities were affected. Some minor operational upsets were occasionally observed (e.g., the VDU in the switch trailer would sometimes require resetting by powering it off and on).

When frame panels were removed and signal filters (analog, digital and subscriber lines) were bypassed, the switch experienced different types of upsets that sometimes affected call processing. Following single pulses, call processing was interrupted for 44% of the events. When call processing was affected, the time of recover of the DMS-100 system ranged from 1.4 to 7.5 minutes with an average of 4 minutes.

Following sets of multiple pulses, call processing was interrupted for 67% of the vents. The average time of recover was 8.5 minutes.

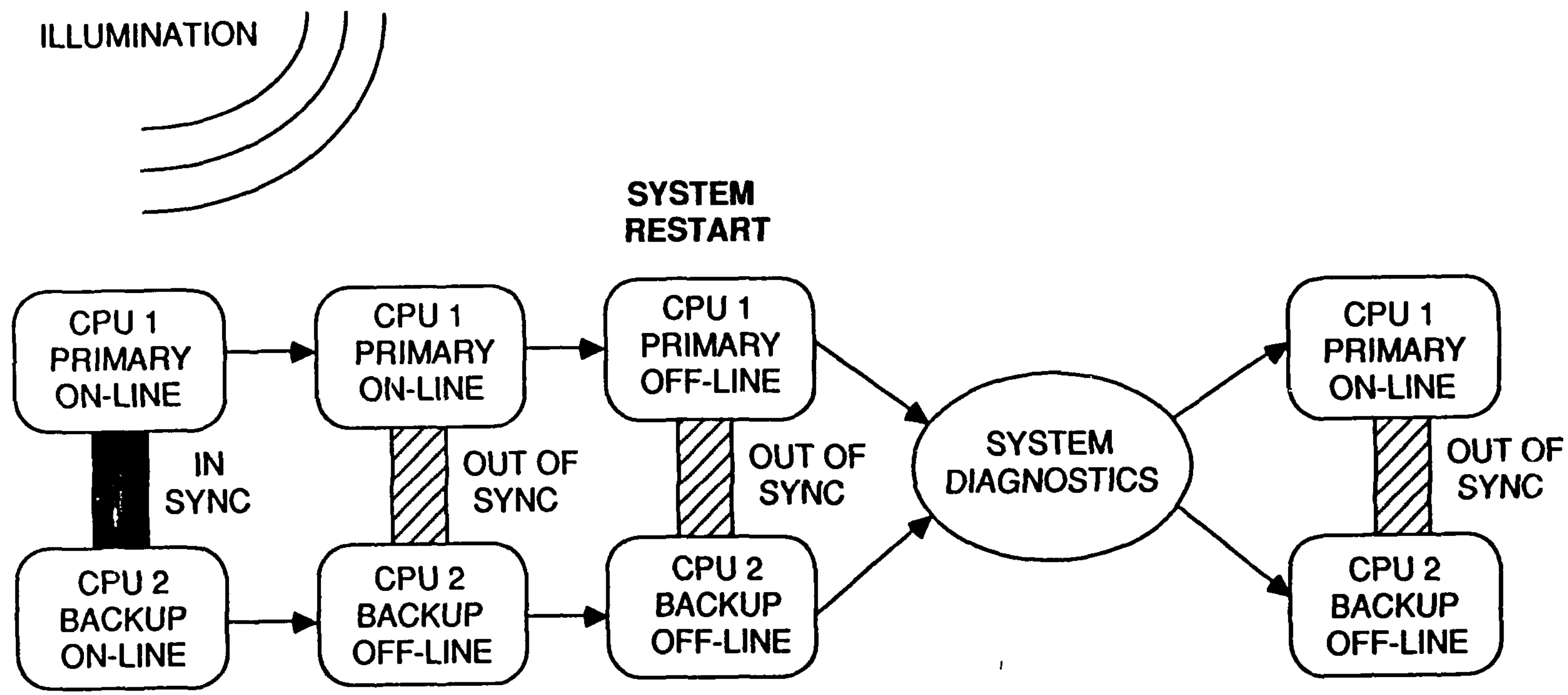



Figure 4-6. System Restart Scenario

One, or rarely two, of the four LTC power convertors (NTZX70AD) occasionally tripped. **Figure 4-7** shows a configuration diagram of NTZX70AD. The unit was affected due to transient coupling into the monitor module (NT6X5340) inside the NT2X70AD. The module contained a supervisory chip to detect an overvoltage condition and cause power converter shutdown for self protection. An HEMP event caused transients in the circuit that were interpreted as an overvoltage condition that then "turned off" the converter unit. **Figure 4-8** shows the circuit diagram of the NT6X5340 monitor module. The first modification was to install filter capacitors in the sensitive module. The result was a decrease in the occurrences of upsets. The supervisory chip was eventually replaced with a pin-compatible chip from another manufacturer during the AESOP testing, and this upset problem never occurred again.

### 4.4.3 AESOP Test Results

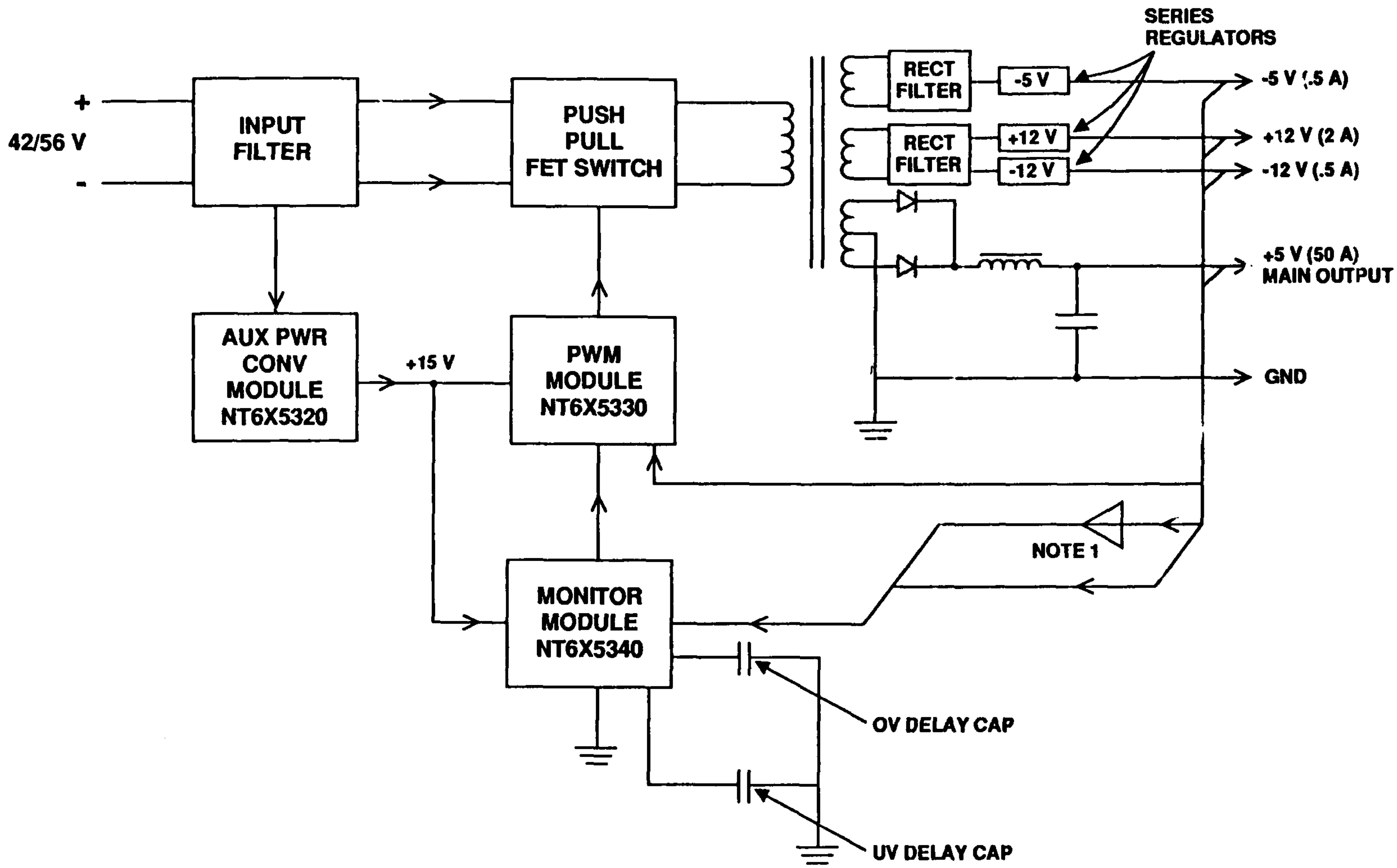
The test article showed inherent HEMP-survivable performance at the AESOP field levels. Critical component failure did not occur; however, call processing upsets occurred at all field strengths, with the EMI shielding removed. The results are discussed below for two switch configurations: "panels on filters on" and "panels off and filters off".

***"Panels On Filters On" Configuration***

The DMS-100 switch was subjected to 237 pulses at the AESOP with field level ranging from 35 to 70 kV/m. With the EMI package in place call processing was hardly affected up to the maximum field level. In the Single Pulsing Mode one pulse out of 17 pulses at the highest field levels (60-70 kV/m) caused one of the Line Concentrating Modules LCMs to go SysB. This meant losing 50% of call processing capability of the switch which recovered in 8 minutes. In the Multiple Pulsing Model (6 pulses, 10-15 minutes apart) at 48 kV/m, the 5th pulse caused a Warm Restart which did not affect calls in progress (preset calls). However, placing new calls was not possible for 2 minutes.

Other upsets, which did not affect call processing, were discovered in the rectifiers. There were 5 AC rectifiers used for the switch. The AC rectifiers converted the 120 VAC to 48 VDC power, which was required to supply constant charge to the battery, which then supplied power to the switch. At all the AESOP field levels, the rectifiers were affected by the pulse illuminations. An overvoltage condition had been detected by the control circuitry of the rectifier causing the "reset" switch to turn off and disabling the rectifier unit. Rectifier operation was regained by manually resetting the switch. At 33 kV/m, two rectifiers were affected. At 45 kV/m, 3 rectifiers were affected, while at 60 kV/m, four rectifiers were affected. The battery supply maintained power to the switch, thus switch operation was not affected. A ceramic capacitor (.01 µf) was eventually installed at an IC interface (U4 pin 8) inside each rectifier to filter out the coupled current that caused the overvoltage condition. This modification cured the rectifier upset problem.

Hardware failure occurred in the keyboard of the MAP video terminal but had no direct impact on the call processing function of the test article. Two keyboard damages occurred at field levels greater than 60 kV/m.




NOTE 1: 4 OUTPUTS ARE MONITORED WITH RESISTOR VOLTAGE DIVIDERS AND FED INTO COMPARATORS IN THE NT6X5340 MODULE. THE ±5 V USES EXTERNAL COMPARATORS. THE ±12 V USE THE INTERNAL COMPARATORS IN THE NT6X5340 MODULE.

Figure 4-7. NT2X70AD Configuration

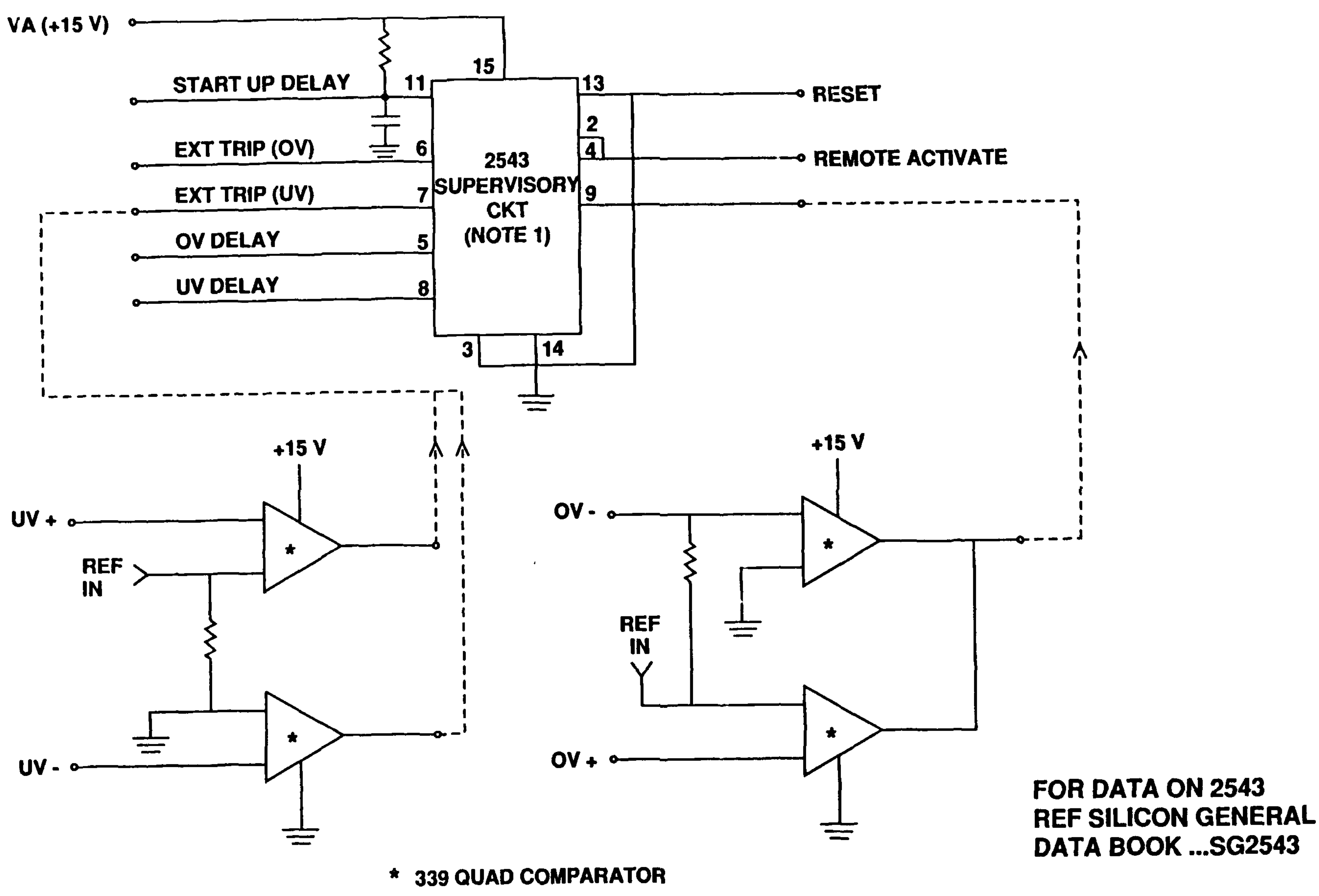



Figure 4-8. Monitor Module (NT6X5340)

### *"Panels Off Filters Off" Configuration*

Without the EMI package, preset calls were lost and call processing was upset for every test pulse. The time of recovery depended upon the field level. **Figure 4-9** shows the average time of recover from single pulses versus field level. REPS results are included for comparison. Vertical bars indicate the standard deviation of the data. The dotted line represents the average time to recover 50% of call processing. In most cases, the operator did not attempt to restore call processing in the shortest time.

**Figures 4-10** and **4-11** show the recovery time results for the upsets for low (10-30 kV/m) and high 30-50 kV/m) field levels, respectively. Two call processing recovery times, 50% and 100%, were recorded for each pulse. The 50% recovery time was recorded when one LCM was returned into operation, and 100% recovery time was recorded when both LCMs were returned into operation as indicated by the MAP outputs.

The two main causes of the operational upsets were power converter shutdown and logic corruption as mentioned above. These upsets and the modifications performed are discussed below:

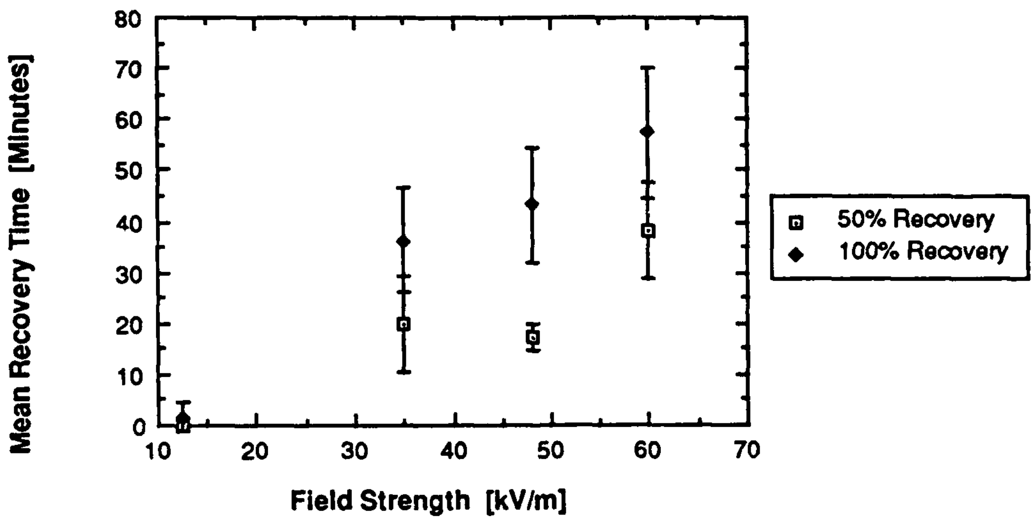



Figure 4-9. Summary of Mean Recovery Times Under HDL Simulators

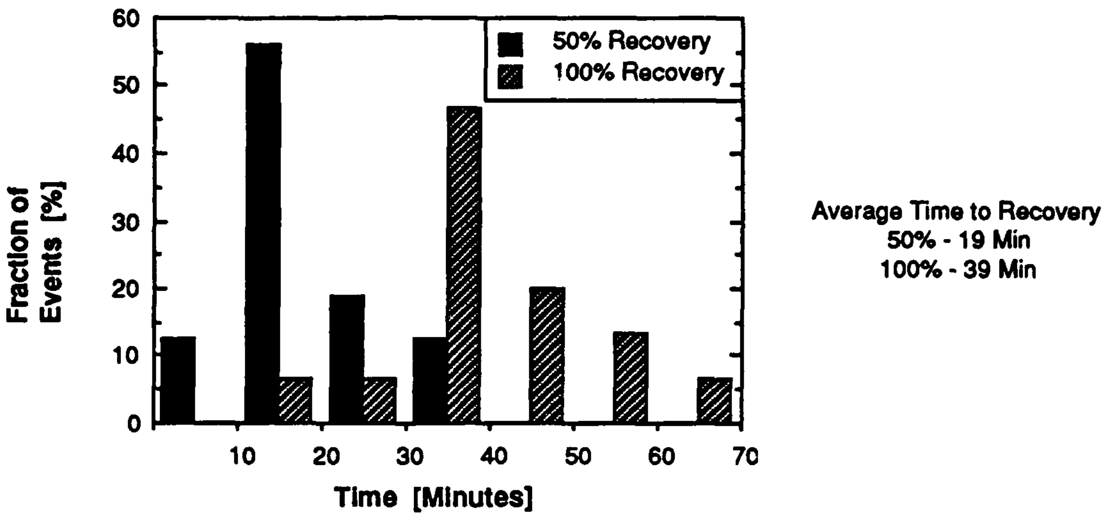



**Figure 4-10. Recovery Time Distribution for Medium HEMP Stresses (30-50 kV/m)**

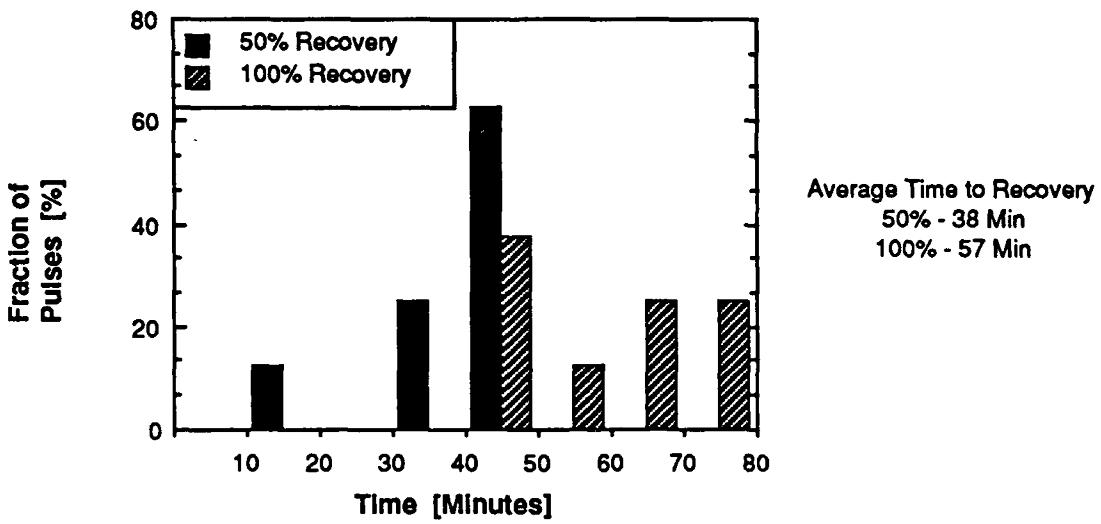



**Figure 4-11. Recovery Time Distribution for High HEMP Stresses (50-70 kV/m)**

Power Converter Shutdown and Modification. This upset problem is similar to the occurrence of the power shutdown in the LTCs. **Figure 4-12** illustrates the component configuration of the NT6X53AA, the power converter unit inside the LCMs. The monitor module (NT6X5340), which is identical to the monitor module in the LTC power converter, detected an overvoltage condition and transmitted a "shutdown" signal to the PWM module, which disabled the operation. Power was restored when a manual reset at the unit was performed. This upset problem was eventually cured when the supervisory chip in the monitor module was replaced with a pin-compatible chip from Unitrode manufacturer.

Memory Upset and Modification. This upset problem was due to logic upset in the processor/memory of the peripheral modules (e.g., LCM, LTC, TM8) which required the transfer of data from the hard disk (or tape) to the random access memory (RAM). Call processing was disabled during the data transfer, and the speed of the transfer depended on the complexity of the system configuration. MAP operator action was required to perform the data transfer. An "autoload" software pack was eventually installed which performed the data transfer and restored 100% call processing automatically.

It is worth mentioning that time of recovery from multiple pulses was not much greater than time of recovery from single pulses. At 60 kV/m the witch recovered from a group of 12 pulses in 66.5 minutes whereas the average time of recovery from single pulses at the same field level was found to be 57.4 minutes.

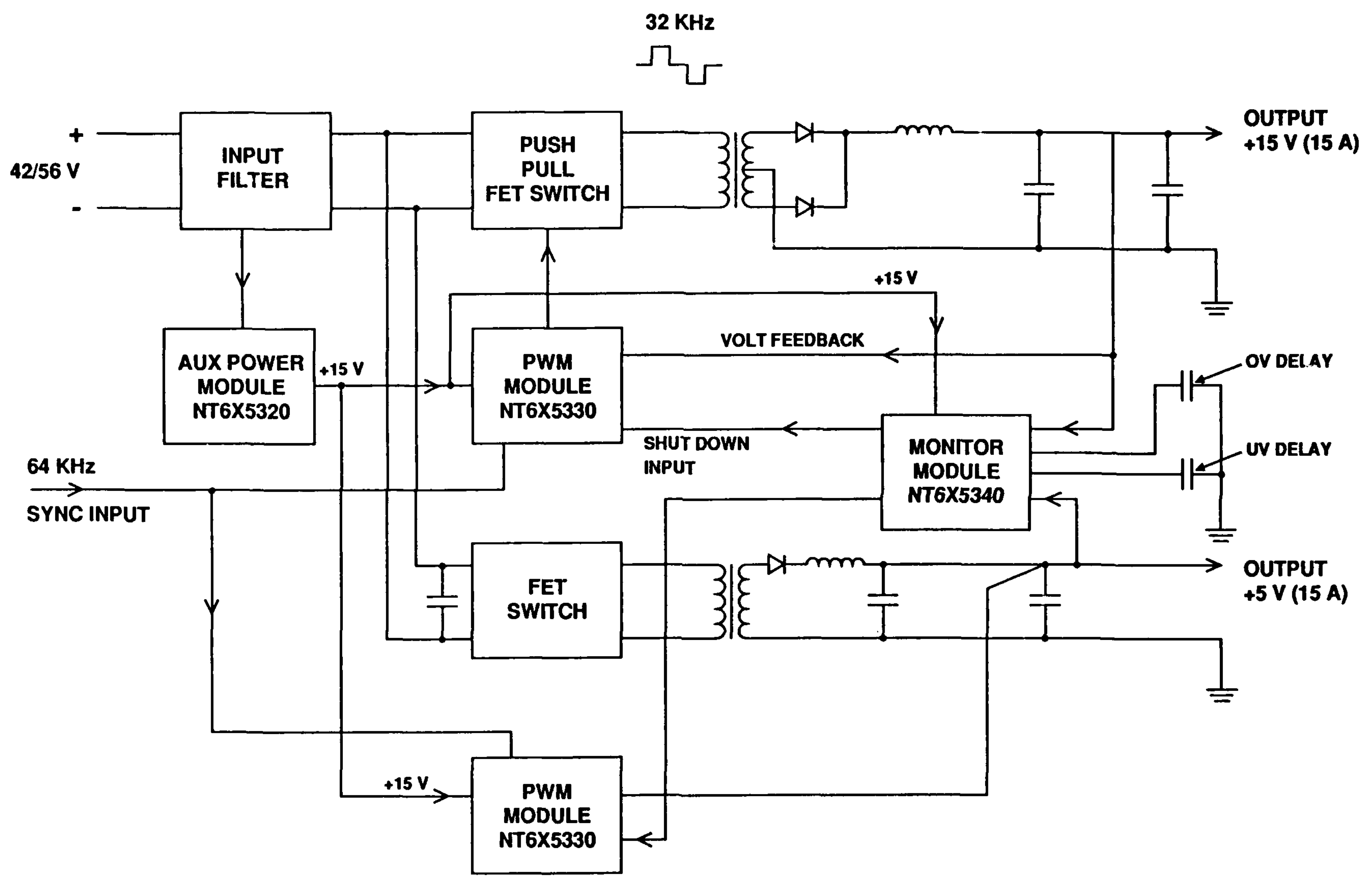



Figure 4-12. NT6X53AA Configuration

# 5.0 MITIGATION TECHNIQUES

## 5.1 INTRODUCTION

As discussed earlier, the DMS-100 switch suffered various upsets and hardware failures (not immediately effecting call-processing operation) during the testing. Various combinations of circuit hardware, software, and shielding were employed to remove these problems. This section reviews these mitigation techniques and their applicability and usefulness for the OMNCS. The mitigation techniques are meant to either correct the problems or to eliminate the need for manual intervention. The remainder of this section is divided into the three types of techniques attempted.

## 5.2 PROBLEMS

The testing of the DMS-100 showed that it is susceptible to HEMP fields. The problems experienced were in the following areas:

- NT5C03BL 50 Amp Rectifiers
- NT2X70AD LTC Power Converters
- NT6X53AA LCM Power Converters
- Logic Corruption in the Processor/Memory of the Peripheral Modules

Recovery from the effects of these problems required operator intervention.

## 5.3 CIRCUIT HARDWARE MITIGATION TECHNIQUES

### 5.3.1 Introduction

Both types of power converter (NT2X70AD and NT6X53AA), as well as the rectifiers employ a shutdown mechanism, which is used for overvoltage and other protection. In all cases, it was suspected and was later confirmed that these circuits were being activated by the HEMP pulse experienced. Although inconvenient, a manual reset could restore the units to normal operation. In addition, the loss of one of the redundant power converter units in the LTC and LCM, or any combination of the rectifiers, does not result in the loss of call-processing operations.

### 5.3.2 Mitigation Techniques

NT5C03BL 50 Amp Rectifiers. The normal input and output leads were well bypassed for EMI, but an optional remote reset was installed that had not been bypassed. This lead ran to the NT5C04CA rectifier control board. A .01μF ceramic capacitor was added between pins 8 and 9 of U4 on this board. There were no rectifier shutdowns after all 5 rectifiers were modified.

NT2X70AD and NT6X53AA Power Converters. Both of these converters use a special supervisory circuit to perform the required shutdown function for protection. The use of additional bypass filter capacitors on the circuit did not prevent the unwanted shutdown upsets. Extensive testing at the WRF test facilities and at the BNR labs confirmed that the shutdowns occurred when an integrated circuit from a

particular manufacturer was used. These circuits were located in the NT6X5340 module. The immediate solution was to replace the Silicon General SG2543 integrated circuit devices in these modules with an Unitrode device. In the long term, BNR-NTI plan to further investigate these circuits to assure that future suppliers of this part meet a specified HEMP requirements.

## 5.4 SOFTWARE MITIGATION TECHNIQUES

### 5.4.1 Introduction

Software upsets were due to logic upsets in the peripheral modules (e.g. LCM, LTC, and TM8). This corrupted the memory in the random access memory (RAM) of these modules. To correct the problem, data transfer is required from a hard disk or tape to the RAM. Call processing through that peripheral module is disabled during the data transfer.

### 5.4.2 Mitigation Technique

The software modification required to solve the problem is an automatic transfer of data from disk to any of the peripheral modules. This should be performed when a "reload restart" condition is encountered. The fix will not prevent the interruption of the call-processing operation. However, it will eliminate the need for manual intervention.

## 5.5 SHIELDING MITIGATION TECHNIQUES

Although NTI offers an EMI protected version of the DMS-100, at an additional cost, switches currently fielded in the PSN and those currently being purchased by the telecommunications industry are mainly of the non-EMI protected version. During the testing of the DMS-100, almost all instances where EMI shielding was included, the switch suffered no operational upsets. Therefore, for total mitigation of HEMP problem, the use of the EMI shielding is recommended.

# 6.0 CONCLUSIONS AND RECOMMENDATIONS

## 6.1 CONCLUSIONS

The results show that the typically unshielded DMS-100, as configured for the test, is inherently survivable against HEMP at up to 60 kV/m peak levels, but vulnerable to system upsets. The system's software allows the system to reconfigure itself in the event of a logic upset, by using redundant units in the system. When the logic upset is more serious than the system can handle, the MAP operator can intervene, usually, by reloading the upset units with "clean" data from the disk or tape. When the system experiences hardware upset in the power subsystem, a manual power reset operation by pushing a button is required to restore power to the units. The most serious upset occurred only once in the test program, which required total "power down" and "power up" recycling to restore system operation. Although no failures were observed, there is a possibility of latent failures, which can only be discovered by a thorough check of the switch.

## 6.2 RECOMMENDATIONS

Recommendations are discussed in this section for providing hardware upset protection, automatic system recovery, and MAP keyboard capability alternatives.

### 6.2.1 Hardware Upset Protection

Existing and future DMS-100 systems should have their power converters and power rectifiers investigated for EMP upsets and protected by implementing the modifications described in this report. The cause of the power converter upset in the test was traced to a sensitive supervisory circuit in the monitor module, and the circuit was replaced with a hardware-compatible circuit. Although the power converter units in the LTC and LCM were found to be vulnerable to upsets, other types of power converters may also be vulnerable. Since other types of peripheral modules exist and may contain different types of power converters, the different types of power converter units in the DMS-100 family should be examined.

For the power rectifier units, a .01 μF ceramic capacitor, installed in the rectifier control board, cured this upset problem. This modification may not be applicable to all power rectifiers in all DMS-100 installations, because the rectifier manufacturers will differ at many installations. Individual examination and analysis is required to ensure the survivability of any DMS-100 that is critical to the NSEP needs of the OMNCS.

### 6.2.2 Auto-Recoverable Software Upset

Even with the hardware modification in place, loss of call processing can still occur above the 10 kV/m level for the unshielded switch. This is due to a logic upset condition called "reload restart" which is caused by memory/logic corruption in the CCC. Without the "autoload" software installed, an operator is required to perform the data transfer from the disk or tape drive units to the peripheral modules. Call processing is fully restored when all the affected PMs are reloaded with "clean" data.

If all MAP terminals are not functional, then call processing will remain disabled without the "autoload" software. Existing and future DMS-100 switches of interest to the OMNCS should have this software capability installed.

### 6.2.3 MAP Keyboard Capability Alternatives

The MAP keyboard exposed to the free field failed during the HEMP test above the 60 kV/m level, but this failure had no immediate effect on call processing. The failure was traced to the damaged transmit/receive circuit in the keyboard. The following lists the alternative future actions that address this finding.

a. No keyboard modification - If the system's call processing can recover automatically and MAP-assisted system reconfiguration is not required, the MAP terminal is not necessary, thus keyboard needs no modification.

b. EMP-protected MAP keyboard at all sites - At least one keyboard at each DMS-100 installation in the NETS should be EMP protected if the requirements in (a) are not met.

c. Spare Keyboard - If an operator will be on site after a HEMP event, a damaged MAP keyboard can be easily replaced with a spare keyboard.

# APPENDIX A. REFERENCES

1. National Communications System, PSN AND NETS Network Level EMP Effects Evaluation: Sensitivity Of Northern Telecom Switches.

2. Booz•Allen & Hamilton Inc., Ottawa Test Experiment DMS-100 HEMP Evaluation, April 1988, UNCLASSIFIED.

3. Booz•Allen & Hamilton Inc., Detailed Test Plan for the NTI DMS-100 Telecommunications Switch (Draft), 7 September 1987, UNCLASSIFIED.

4. Northern Telecom Inc., Traffic Generator Analog (TGA) User's Guide, January 1987, UNCLASSIFIED.

# APPENDIX B. PRETEST SUSCEPTIBILITY ANALYSIS

## B.1 INTRODUCTION

The pretest susceptibility testing and analysis was carried out by BNR at the BNR Corkstown labs in Ottawa, Canada. The test results were presented on April 29, 1987 and were included in a BNR internal report. The tests were conducted to determine susceptibility of a major DMS-100 module to simulated HEMP pulses.

The BNR laboratory DMS-100 testing focused on the line and trunk interfaces using an operating Remote Line Concentrating Module (RLCM). The RLCM was connected to a DMS-100 Captive Office located at the BNR Carling lab in Ottawa via two T1 lines and was equipped with the EMI package; shielding panels and filter bulkhead. The RLCM was also equipped with a complement of line cards, which were connected to a Main Distribution Frame (MDF), line protectors and a phone board to allow calls to be placed during the test. **Figure B-1** shows details of various shelves of the RLCM frame. The operational status of the RLCM frame was monitored using the Maintenance and Administration Position (MAP) connected to the host captive office.

## B.2 TEST METHODS

Lab investigations of RLCM HEMP vulnerability and susceptibility performance were carried out using radiated and conducted methods in the EMP lab at BNR Corkstown.

The EMI protected RLCM frame was subjected to radiated EMP fields inside a Transverse Electromagnetic (TEM) cell that simulated HEMP plane waves. Various elements of the EMI package were then removed in stages to study separately the protection that each element offered.

Since only a limited length of system external cables could be illuminated inside the TEM cell, the RLCM frame was also subjected to supplementary conducted injection tests.

During EMP testing two personnel were needed to apply the EMP pulse, monitor the MAP and printer and in some situations to place several calls to simulate traffic. In most cases several calls were placed before applying EMP pulses and the status of these calls were checked after each pulse.

The pulsing frequency varied depending on the expected operational response of the system to EMP pulses. With the system fully protected (EMI protected RLCM and shielded external cables), sets of 200 pulses with several seconds between successive pulses were used. In other cases, the time between consecutive pulses was set to be approximately one minute. When operational upsets occurred the system was left to recover on its own before applying additional pulses.

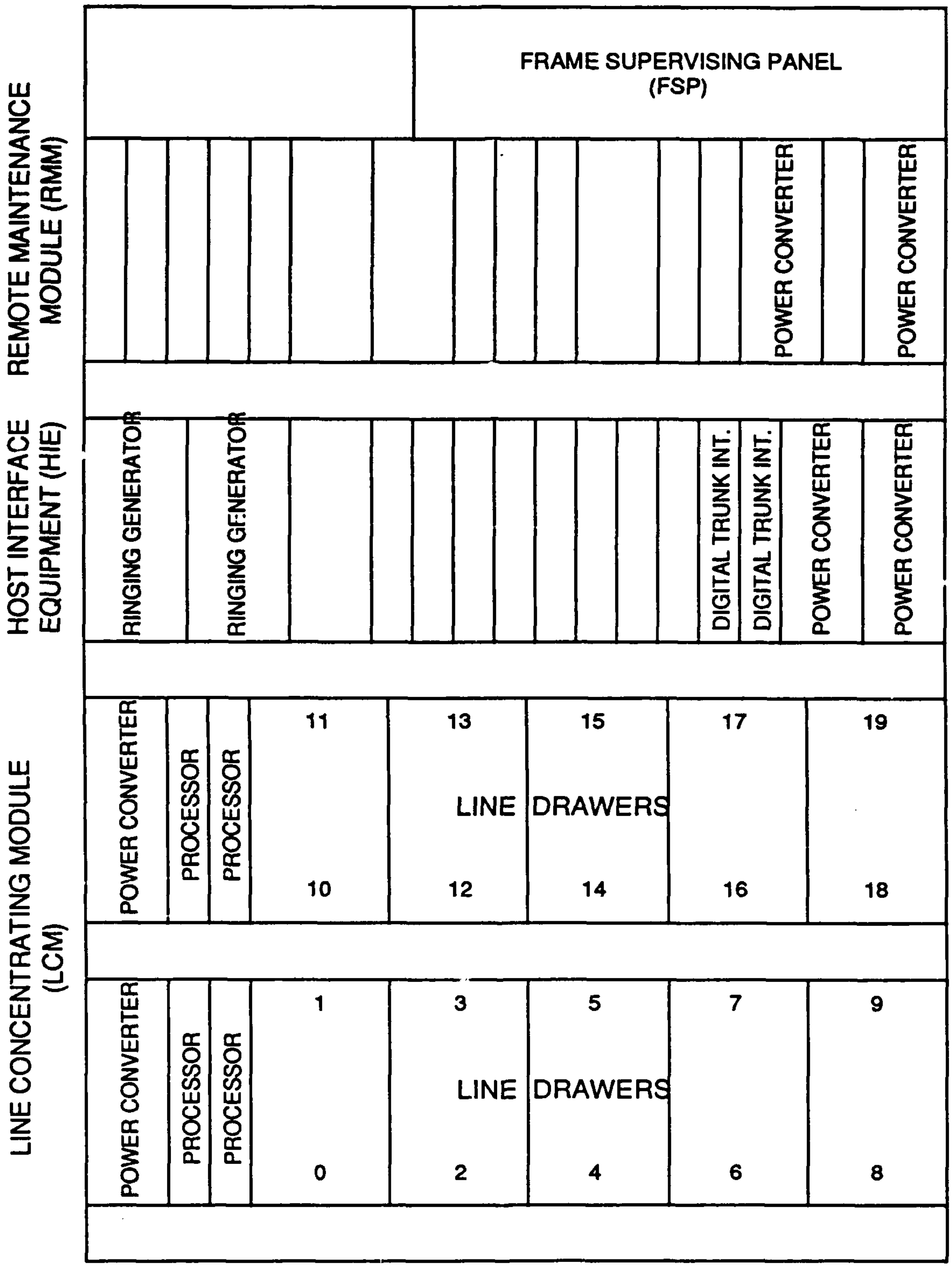



**Figure B-1. Remote Line Concentrating Module (RLCM)**

## B.3 RADIATED TEM CELL TESTING

### B.3.1 Test Description and Configurations

The RLCM test frame was subjected to numerous radiated pulses using an Instruments for Industry high voltage pulse TEM cell. The Electromagnetic Pulse (EMP) was generated by a Physics International FRP-50 EMP Pulser. **Figure B-2** shows a sketch of the RLCM frame laid on its back inside the TEM cell. The distance between the TEM cell middle plate and the RLCM front face was 15 inches. All external cables were shielded in a special duct. The shielding duct was used to exclude the applied radiated pulse from the external cables so that the response of the RLCM shielded or unshielded frame could be studied in isolation. The electric field strength inside the TEM cell was measured by Elgal D-dot/E-field sensor with Hewlett-Packard 54200A Digitizing Oscilloscope.

Various test configurations were used during the TEM cell testing in order to study separately the protection that each element of the EMI package offered. These configurations are outlined as follows, where the word "system" refers to the RLCM frame and external cables:

| | Configuration |
|---|---|
| a - System with full EMI protection | A |
| b - System with partial EMI protection | |
| (i) Shielding panels off | B |
| (ii) External cables exposed (panels on): | |
| - All signal and power filters on | C |
| - Two signal filters off (0A, 1A) | D |
| - All signal filters off | E |
| - All signal and power filters off | F |
| c - System without EMI protection | G |

### B.3.2 Test Results

**Figure B-3** summarizes the results of the TEM cell testing for different configurations. The bars shown in the figure indicate the range of the EMP field during which auto-recoverable or manually-recoverable upsets occurred. The applied EMP field ranged from 26 kV/m to about 110 kV/m for all configurations. The total number of pulses applied in each configuration is included at the bottom of Figure B-3.

In the first set of tests (Configuration A) the RLCM was equipped with the EMI package and external cables were protected in the cable ducting. Since operational upsets were not expected in this case, sets of 200 pulses were applied with several seconds between successive pulses. Figure B-3 shows that only one operational upset occurred during the 2000 applied pulses. The system recovered automatically, from this single upset, in 2 seconds and call processing was not affected.

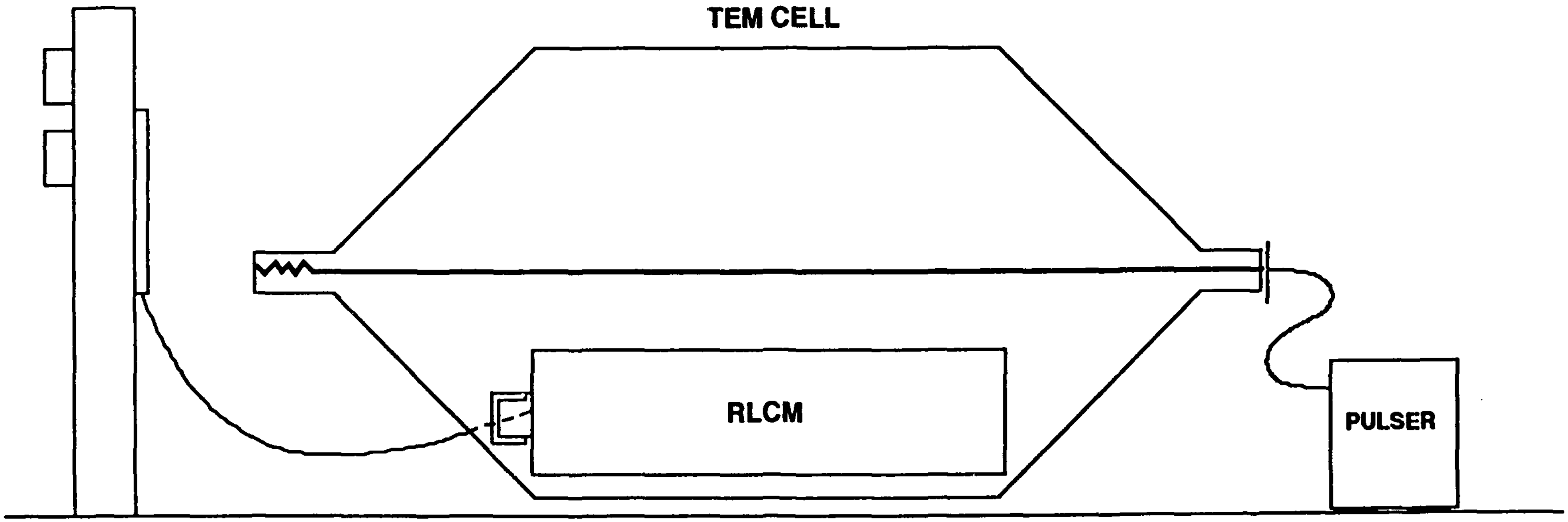



Figure B-2. TEM Cell Setup

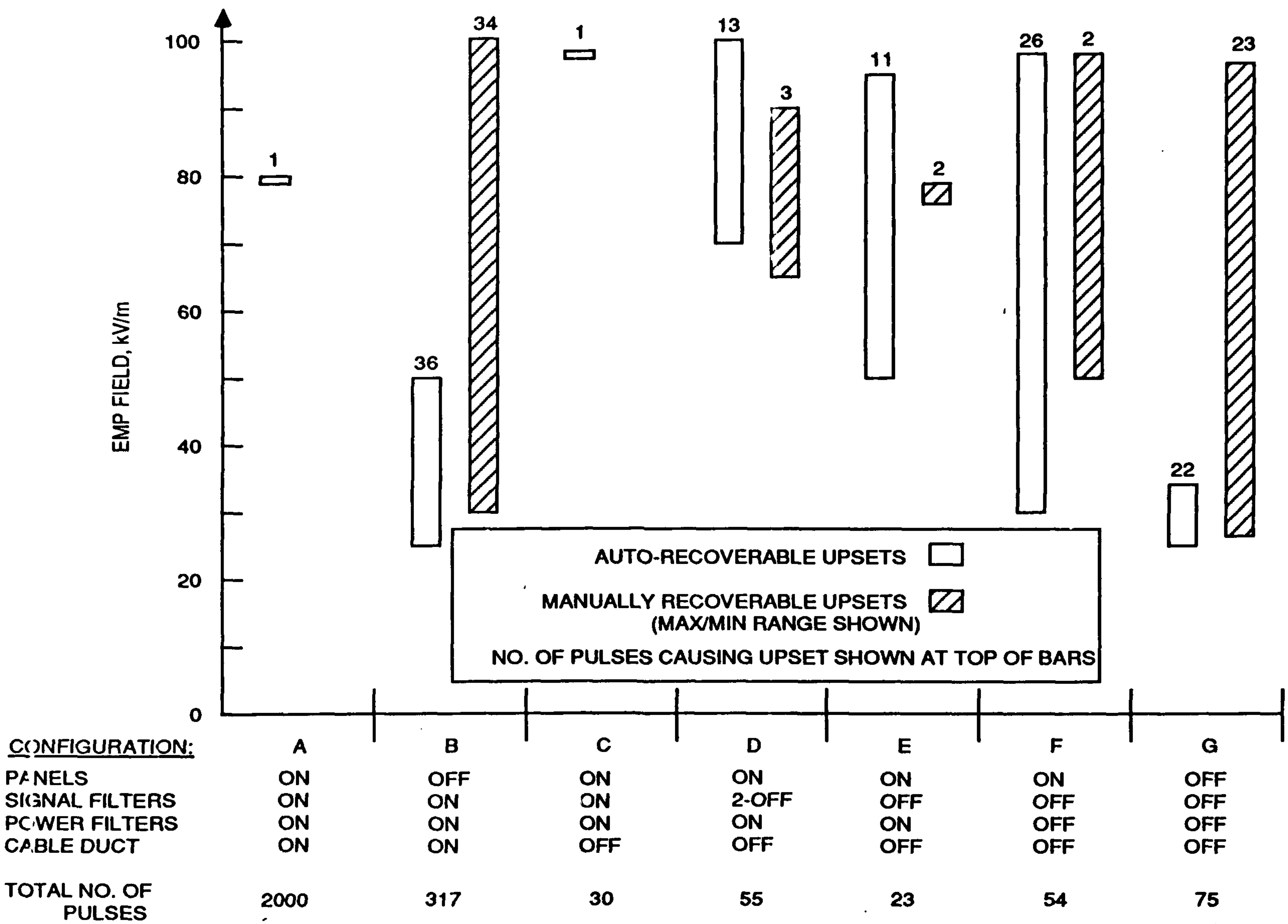



**Figure B-3. RLCM Upset Distribution (Radiated TEM Cell Experiment)**

In Configuration B, shielding panels are removed. **Figures B-3 and B-4** demonstrate the significant shielding effectiveness of the frame panels. At 50 kV/m field level and above the percentage of pulses causing upset reaches 100%. As the EMP field exceeds 80 kV/m the probability of tripping both power converter units of the Remote Maintenance Module (RMM) increases.

In Configuration C, panels are on, but the cable duct is removed to expose system cables. Applying 30 pulses caused only one auto-recoverable upset that did not affect call processing (Exhibits B-3 and B-5). The effect of bypassing two signal filters in Configuration D is shown in **Figure B-5**. The results of bypassing all signal filters in Configuration E are shown in **Figure B-6**. In Configuration F, the power filters, which are standard on all switches, are also bypassed and this result is shown in **Figure B-7**.

Configuration G represents the worst case where all filters and shielding panels are removed and external cables exposed. The probability of upsetting the system in this case reaches 100% at about 35 kV/m as shown in **Figure B-8**.

The results of the TEM cell radiated tests confirm the effectiveness of the EMI package panels and filters. The results also indicate that the damage level from direct radiation is above the 110 kV/m level, since no damage was recorded during the TEM cell testing.

The time of recovery was recorded in most cases. The time of recovery to full system operation is shown in **Figure B-9** as a function of the EMP field for the worst case configuration (G). Dotted lines indicate average time of recovery while vertical solid lines shown the maximum/minimum range. The time required to fully restore call processing is appreciably less than the time of recovery shown in **Figure B-9**.

## B.4 CONDUCTED INJECTION TESTING

### B.4.1 Test Description and Configurations

The RLCM was also subjected to supplementary conducted injection tests. Since only a limited length of system external cables could be illuminated inside the TEM cell, the conducted injection testing was needed to simulate the actual installations where long external cables are exposed to the HEMP field. The conducted injection testing utilized an ESD generator that discharged through a short wire which was coupled to the cables under test using two ferrite cores. A parallel plate capacitor of 1 nF was connected across the ESD generator to enhance the current level. The resultant injected currents were measured using AIL TECH 94430-1 current probes. A sketch of the test setup in shown in **Figure B-10**. A Hewlett-Packard 54200A Digitizing Oscilloscope was used to determine the peak-to-peak (p-p) current levels.

Various system external cables were conductively injected using core injection. Different configurations were used depending on the number of cables injected and whether their filters were bypassed or not. These configurations are outlined as follows:

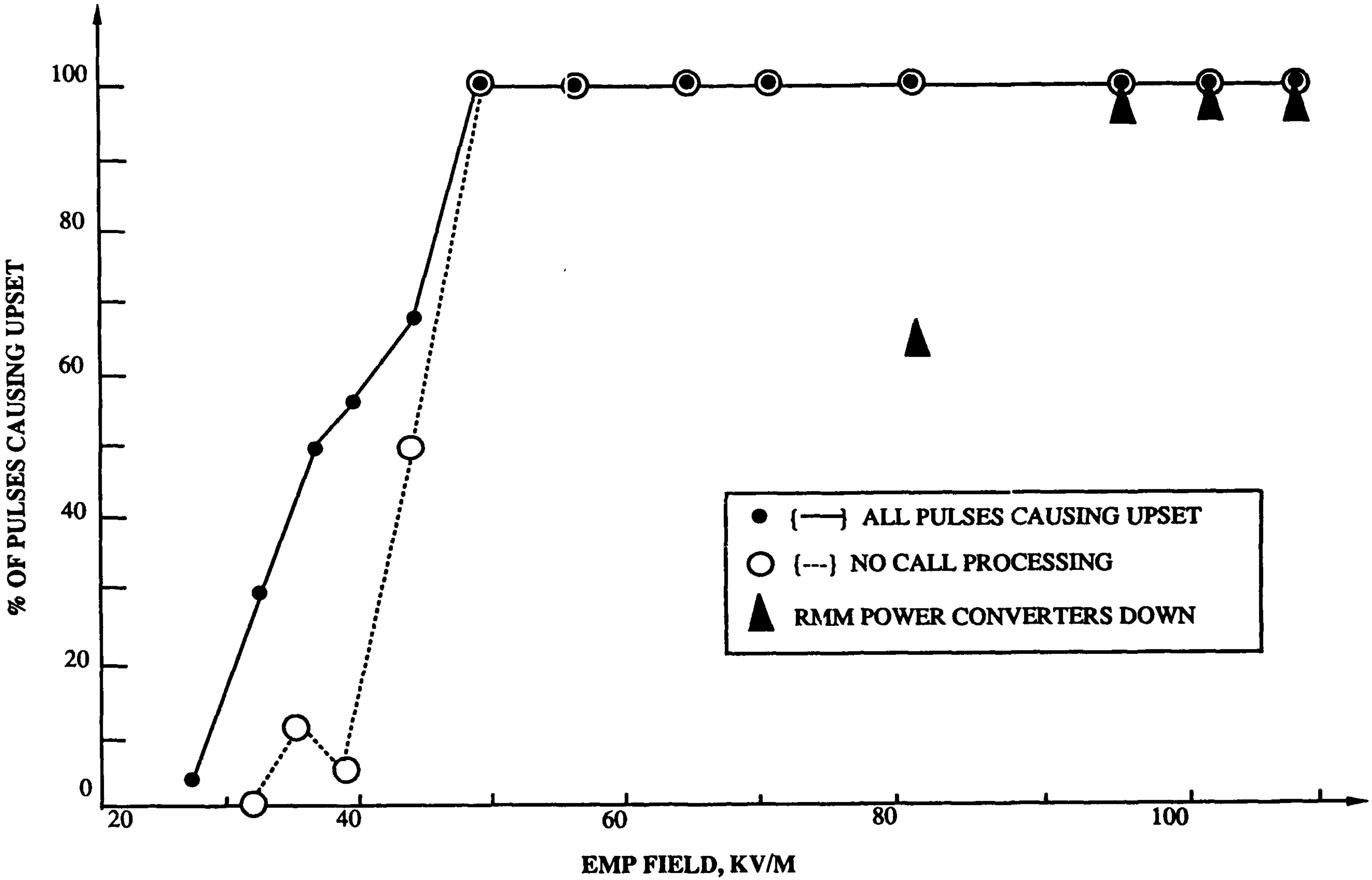



**Figure B-4. Radiated Experiment Result (Configuration B)**

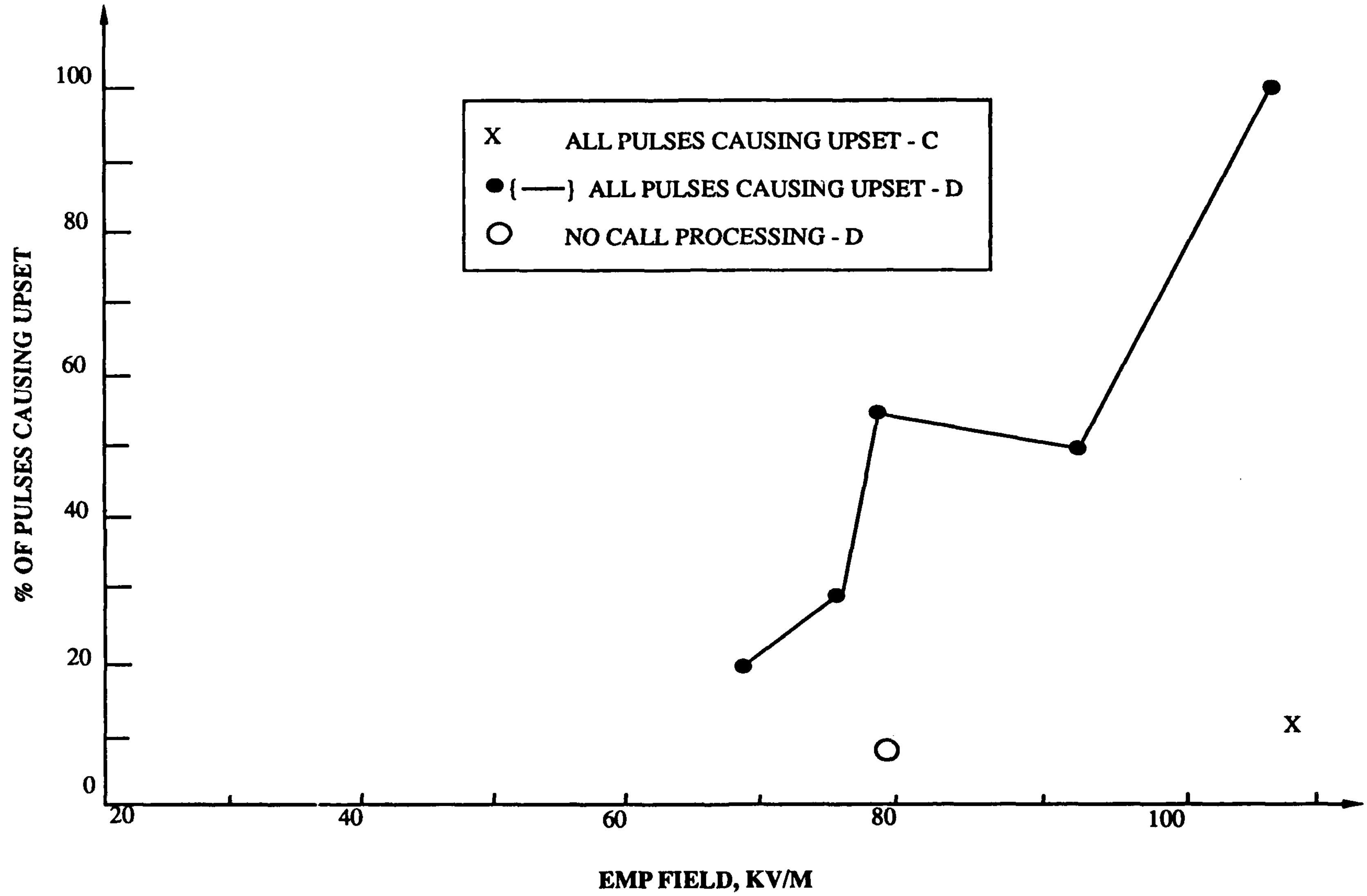



Figure B-5. EMP Field Upset Distribution (Configurations C and D)

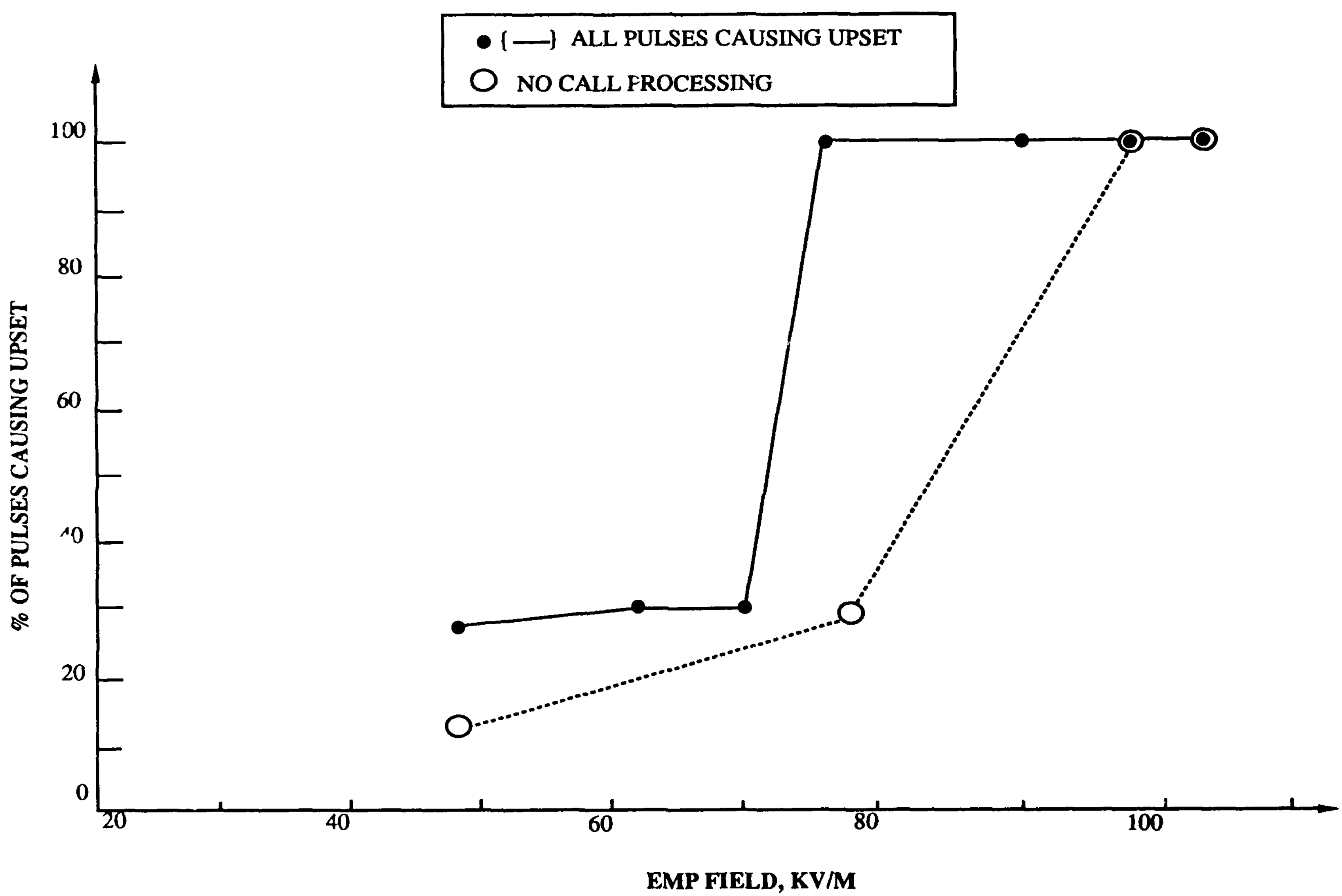



Figure B-6. EMP Field Upset Distribution (Configuration E)

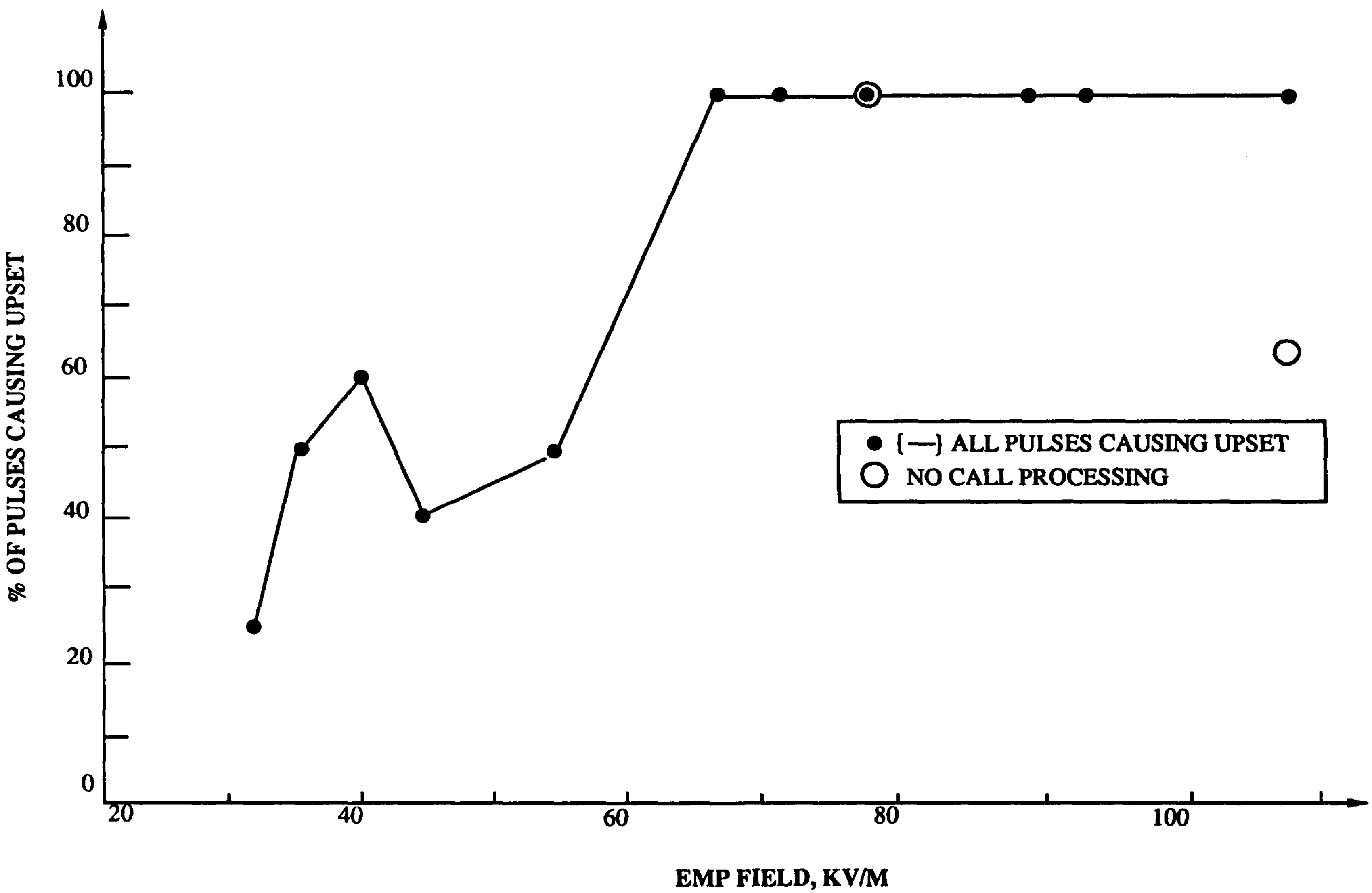



Figure B-7. EMP Field Upset Distribution (Configuration F)

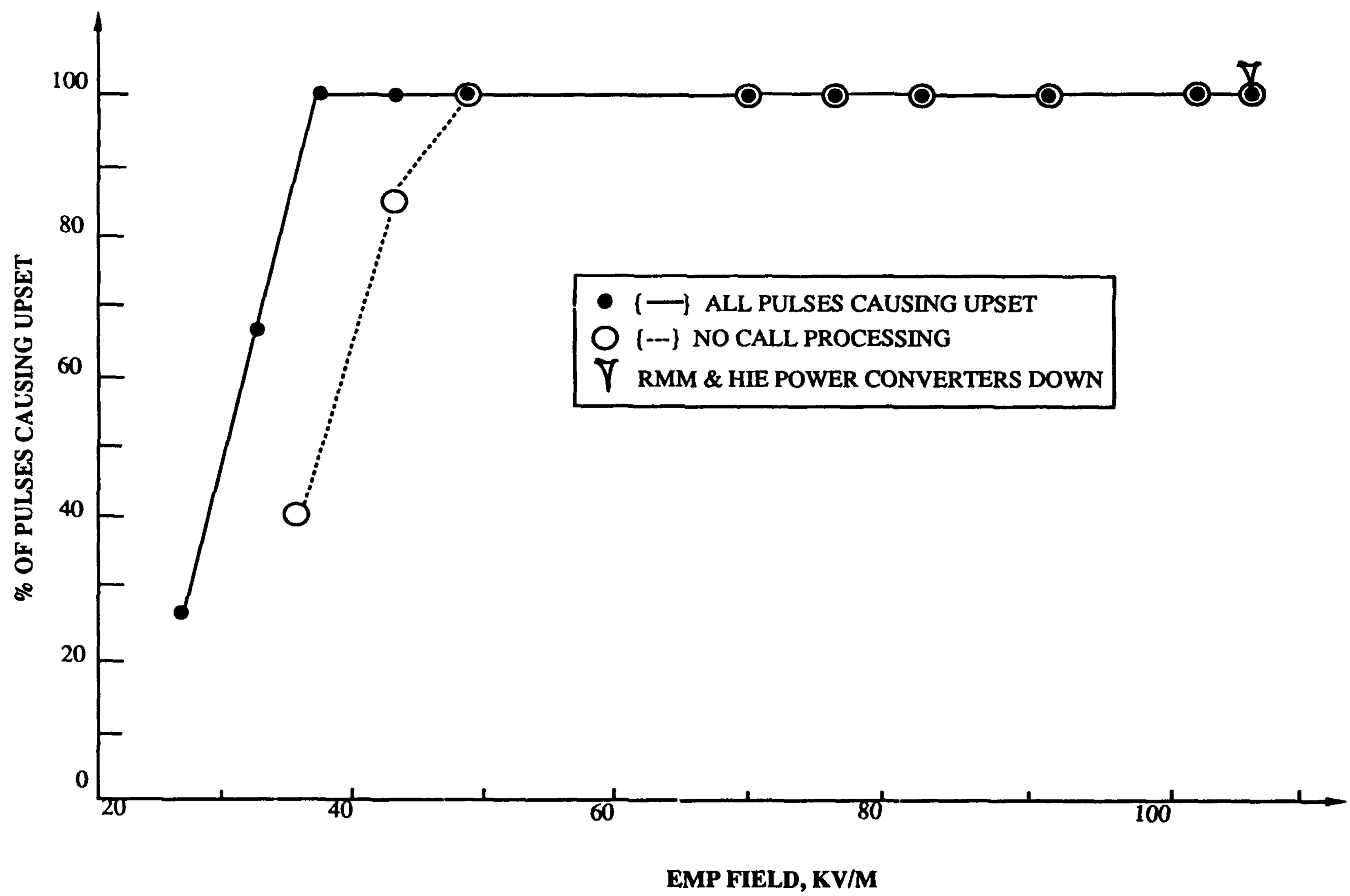



Figure B-8. EMP Field Upset Distribution (Configuratin G)

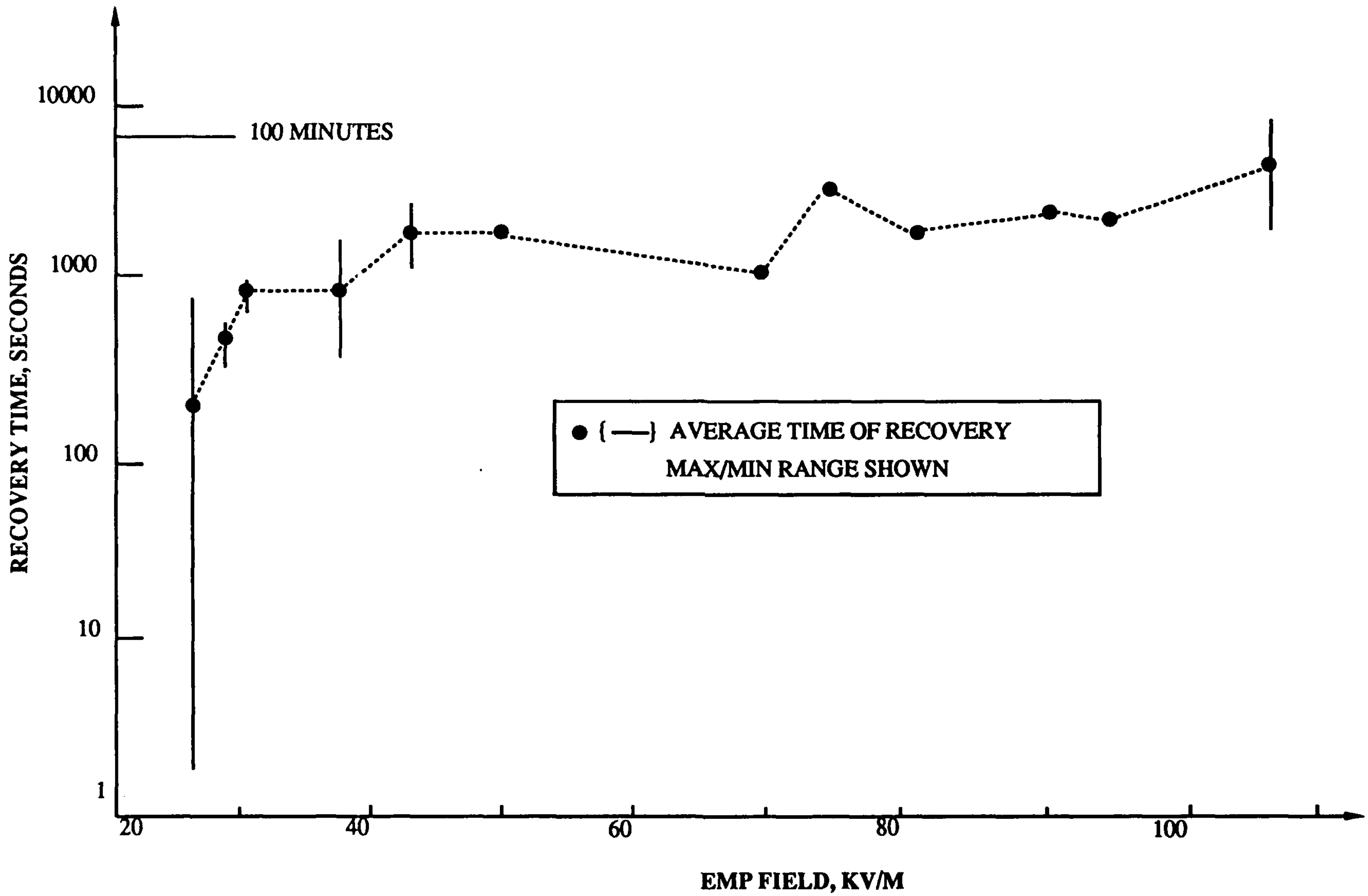



Figure B-9. Time of Recovery to Full System Operation (Configuration G)

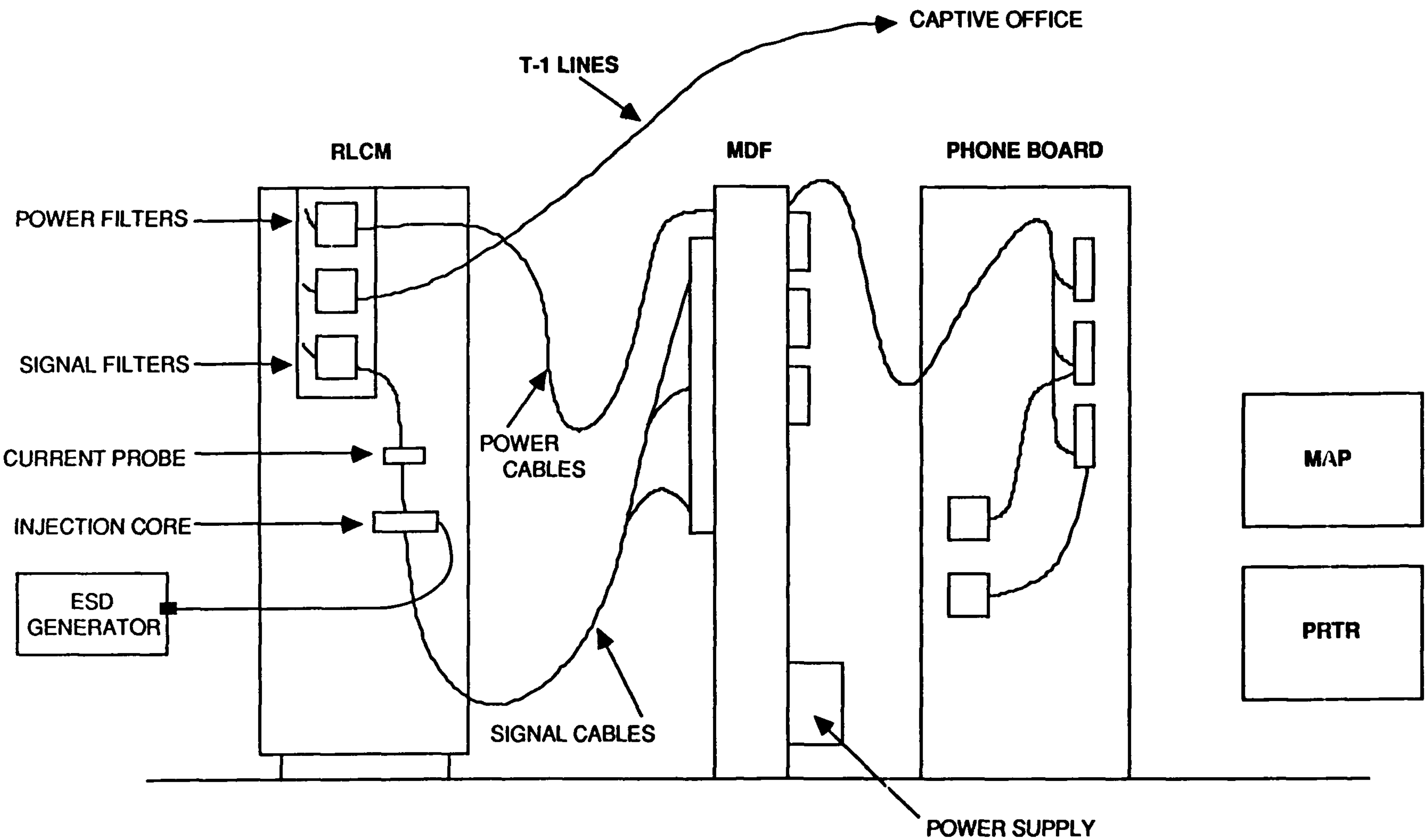



Figure B-10. Current Injection Setup

| Cables Injected | | | Configuration |
|---|---|---|---|
| a - | All signal cables - filters on | | A |
| b - | Two signal cables (0A, 1A) | | |
| | (i) | Filters on | B |
| | (ii) | Two signal filters off (0A, 1A) | C |
| c - | One signal cable (0A) | | |
| | (i) | Filters on | D |
| | (ii) | One signal filter off (0A) | E |

### B.4.2 Test Results

**Figure B-11** summarizes the results of the conducted injection tests for different configurations. The bars shown in the figure indicate the range of the average injected current per signal conductor pair where auto-recoverable or manually-recoverable upsets occurred. In Configurations B and D where no upsets were recorded, dotted lines show the level of the maximum current injected.

In Configuration A all the 26 signal cables (16 pair each) were injected with 33 pulses at current levels 0.43 to 0.61 A (p-p)/pair. Only one pulse at the highest level caused an auto-recoverable upset that did not affect call processing.

In Configuration B two signal cables (0A, 1A) were injected with p-p currents up to 5.47 A/conductor pair without upsetting the system. When filters connected to 0A, 1A were bypassed (Configuration C), auto-recoverable and manually-recoverable upsets occurred as shown in **Figures B-11** and **B-12.**

For further increase of current level/pair, one signal cable (0A) was injected which corresponds to Configuration D. No upset was recorded at current levels up to 9.17 A (p-p)/pair. When the filter connected to 0A was bypassed (Configuration E), auto-recoverable and manually-recoverable upsets were recorded as shown in **Figures B-11** and **B-13**. A current level of 5.19 A (p-p)/pair was reached in this case.

## B.5 CONCLUSIONS

A. The TEM cell radiated tests showed that the RLCM with the EMI package could withstand a radiated field of up to 110 kV/m without any significant upset. Thus it was anticipated that a similarly hardened DMS-100 system would meet the 70 kV/m field level at HDL.

B. With the EMI package removed, the RLCM experienced various types of upsets during TEM cell radiated testing. The threshold of upsets involving loss of call processing was 35 kV/m.

C. The conducted injection tests on line interface cables showed that the RLCM with the EMI package could withstand peak-to-peak current levels almost 3 times higher than those expected in full system EMP tests without damage or upset.

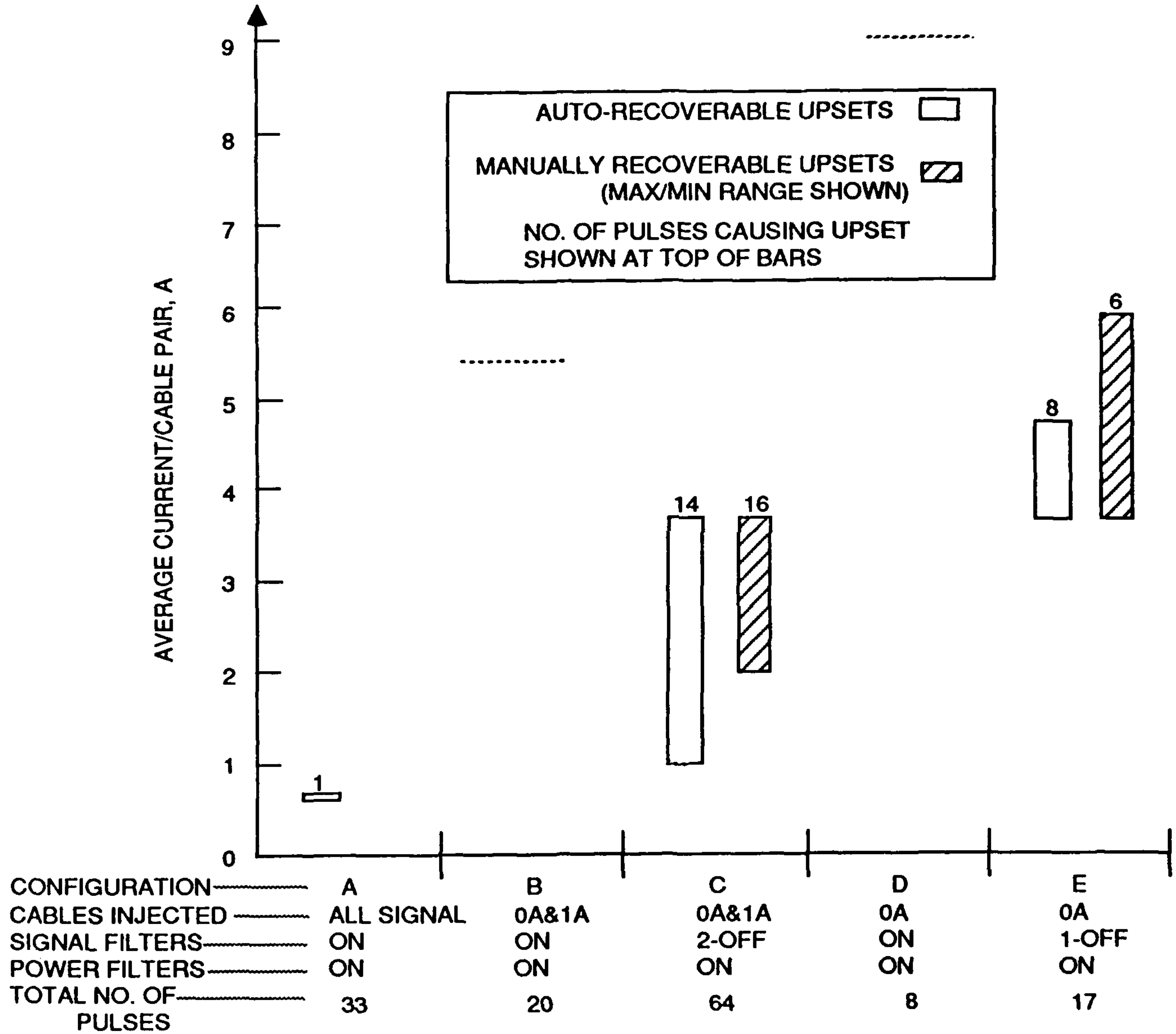



Figure B-11. RLCM Upset Distribution (Current Injection Experiment)

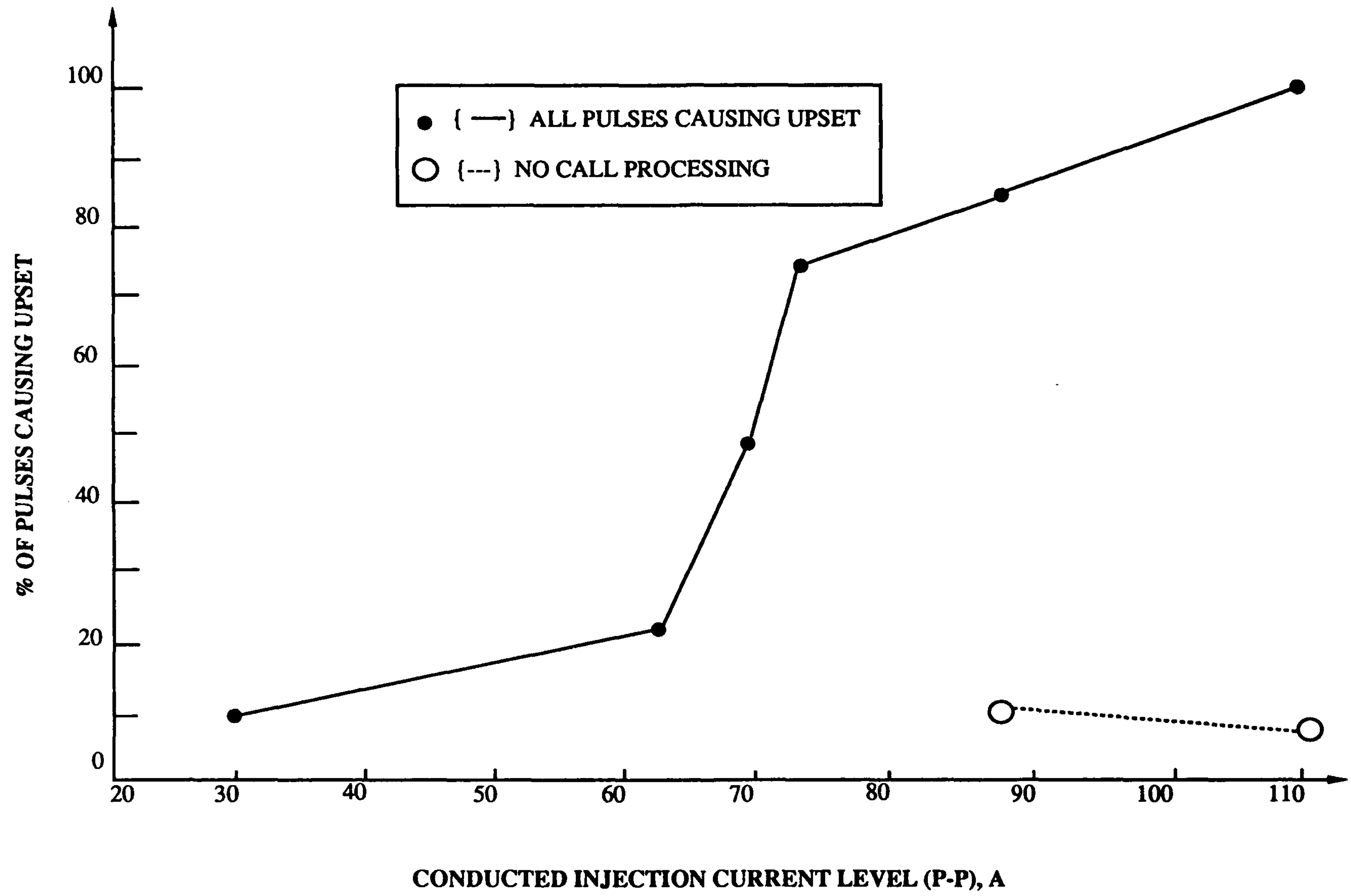



Figure B-12. Current Injection Upset Distribution (Configuration C)

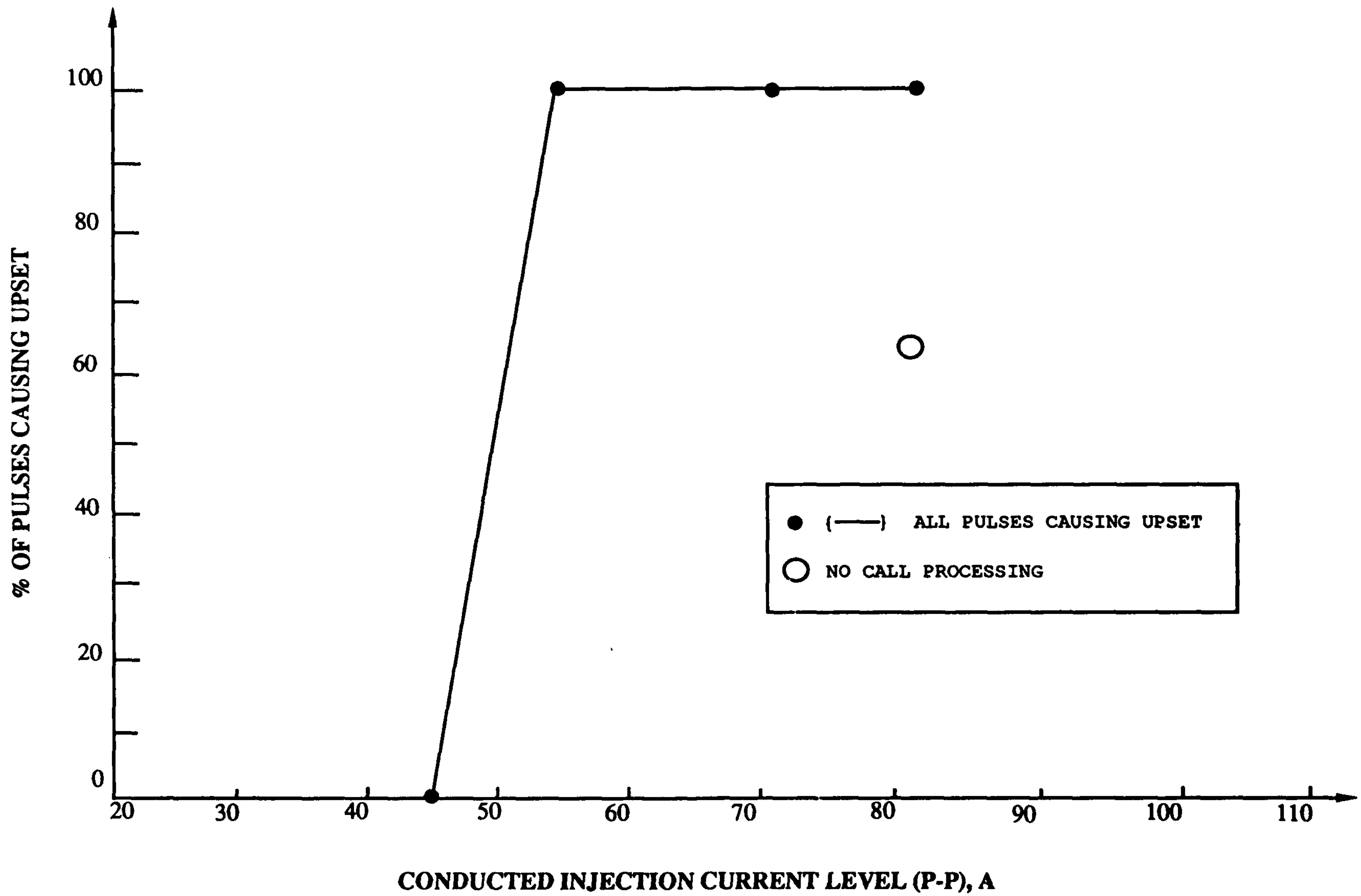



Figure B-13. Current Injection Upset Distribution (Configuration E)

D. The conducted injection tests on line interface cables showed that the RLCM with the EMI package removed was subject to upsets involving loss of call processing at injection levels corresponding to fields of 50 kv/m and up.

E. Extrapolation of the RLCM results to the full DMS-100 system configuration at HDL was made with qualification. Shielding provisions for all frames in the DMS were virtually identical, and the technology of the circuitry present in the line module processor, related memories and power converters was representative of that used in other parts of the system. Consequently, it was estimated that the full system behavior would exhibit similar upset thresholds as found for the RLCM, however, the type and degree of upset and associated recovery time were expected to be more complex for the unprotected full system than for the unprotected RLCM.

# APPENDIX C. DETAILED TEST RESULTS

This appendix presents the results of the HEMP testing of the DMS-100 in tabular form. The data are separated into different configurations and different simulators.

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery 50% C.P. | 100% C.P. |
|---|---|---|---|---|
| 2 | 11.6 | | | ** |
| 3 | 11.9 | | | ** |
| 4 | | | | ** |
| 5 | 11.9 | | | ** |
| 6 | 12.1 | | | ** |
| 7* | 12.2 | LTC Troubles | | ** |
| 8 | 12.3 | | | ** |
| 9* | 12.2 | LTC1-0 SysB | | ** |
| 10* | 12.4 | LCM0-0 SysB | | ** |
| 11 | | | | ** |
| 12 | | | | ** |
| 13 | | | | ** |
| 14 | 12.0 | | | ** |
| 15 | | | | ** |
| 16 | | | | ** |
| 18 | | | | ** |
| 19 | | | | ** |
| 20 | | | | ** |
| 21 | | | | ** |
| 22 | | | | ** |
| 23-25 | | | | ** |
| 26-28 | | | | ** |
| 29-31* | | TM8-1 SysB | | ** |
| 32-34 | | | | ** |

TABLE C-1

Configuration A: Panels On, Filters On

** Call Processing (C.P.) was not interrupted

* Trunk Filters Off & Trunk Back Panels Off

12 kV/m

## REPS TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery 50% C.P. | Time of Recovery 100% C.P. |
|---|---|---|---|---|
| 182 | 12.5 | LCM1 SysB (50% C.P.) | | 1.4 |
| 183 | 12.6 | Drop SYNC | | ** |
| 184 | 12.4 | LTC0 SysB (50% C.P.) | | 2.4 |
| 185 | 12.2 | LTC0-0 & LTC1-0 SysB | | ** |
| 186 | 12.4 | Drop SYNC | | ** |
| 187 | 12.4 | LTC0 SysB (50% C.P.) | | 4.6 |
| 191 | 12.5 | Drop SYNC | | ** |
| 192 | 12.5 | Cold Restart | 7.4 | 7.5 |
| 193 | 12.4 | Drop SYNC | | ** |
| 188-190 | 12.7 | LTC0-0 & LTC1-0 Sys B | | ** |
| 194-196 | | Warm Restart | 1.7 | 4.2 |
| 197-201 | 12.6 | Cold Restarts | | 12.8 |

TABLE C-2

Configuration C: Panels Off, Filters Off

** Call Processing (C.P.) was not interrupted

12 kV/m

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery | |
|---|---|---|---|---|
| | | | 50% C.P. | 100% C.P. |
| 707 | 34.1 | | | ** |
| 708 | 35.7 | Transient Mismatch | | ** |
| 709 | 35.4 | Transient Mismatch | | ** |
| 710 | 35.4 | Transient Mismatch | | ** |
| 711 | 35.2 | Transient Mismatch | | ** |
| 712 | 34.1 | Transient Mismatch | | ** |
| 713 | | | | ** |
| 714 | 34.5 | | | ** |
| 715 | 35.3 | | | ** |
| 717 | 34.4 | Transient Mismatch | | ** |
| 718 | | | | ** |
| 719 | | | | ** |
| 720 | 35.2 | | | ** |
| 721 | 35.7 | Transient Mismatch | | ** |

TABLE C-3

Configuration A: Panels On, Filters On

** Call Processing (C.P.) was not interrupted

35 kV/m

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery 50% C.P. | Time of Recovery 100% C.P. |
|---|---|---|---|---|
| 729 | | Transient Mismatch | | ** |
| 730 | 48.3 | Transient Mismatch | | ** |
| 731 | 47.2 | | | ** |
| 732 | 47.2 | LTC0-1 SysB | | ** |
| 733 | 47.9 | | | ** |
| 734 | 47.0 | LTC0-0 & LTC1-1 SysB | | ** |
| 735 | 46.6 | LTC1-1 SysB | | ** |
| 736 | | | | ** |
| 737 | 46.5 | LTC1-1 SysB | | ** |
| 722-728 | Ave. 48.5 | Warm Restart (Once)* | | 2.0 |

TABLE C-4

Configuration A: Panels On, Filters On

** Call Processing (C.P ) was not interrupted

* Preset Calls were not affected

48 kV/m

# AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery | |
|---|---|---|---|---|
| | | | 50% C.P. | 100% C.P. |
| 738 | 62.4 | Drop SYNC | | ** |
| 739 | | Drop SYNC | | |
| 741 | 60.4 | Drop SYNC | | ** |
| 743 | 59.7 | | | ** |
| 744 | 58.7 | LCM1 SysB (50% C.P.) | | 8.1 |
| 745 | | LTC0-1 SysB | | ** |
| 746 | 60.5 | LTC1-1 SysB | | ** |
| 747 | 59.2 | Drop SYNC | | ** |
| 748 | | | | ** |
| 749 | | Drop SYNC | | ** |
| 750 | 60.5 | Drop SYNC | | ** |
| 751 | 60.8 | LTC1-1 & LTC0-0 SysB | | ** |
| 752 | 60.8 | LTC0-0 SysB | | ** |
| 753 | 58.9 | LTC0-0 SysB | | ** |

TABLE C-5

Configuration A: Panels On, Filters On

** Call Processing was not interrupted

60 kV/m

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery | |
|---|---|---|---|---|
| | | | 50% C.P. | 100% C.P. |
| 754 | 67.3 | Drop SYNC | | ** |
| 755 | 69.1 | LTC0-0 SysB | | ** |
| 756 | 68.5 | LTC0-0 & LTC1-0 SysB | | ** |

TABLE C-6

Configuration A: Panels On, Filters On

** Call Processing was not interrupted

68 kV/m

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery | |
|---|---|---|---|---|
| | | | 50% C.P. | 100% C.P. |
| 757 | 37.1 | Reload Restart | 12.0 | 15.7 |
| 758 | 34.6 | Reload Restart | 17.8 | 20.0 |
| 759 | 34.6 | Cold Restart | 3.6 | 16.1 |
| 760 | 34.2 | Cold Restart | 8.0 | 15.7 |
| 761 | 34.9 | Reload Restart | 19.6 | 24.3 |
| 762 | 34.4 | Reload Restart | 14.7 | 32.2 |
| 765 | 35.3 | Cold Restart | 15.5 | |
| 766 | 36.2 | Reload Restart | 19.8 | |
| 767 | 35.7 | Cold Restart | 11.0 | 18.2 |
| 763-764 | Ave. 34.9 | Cold Restarts | 16.5 | |
| 768-770 | Ave. 35.4 | Cold Restarts | 7.6 | 13.3 |
| 771-773 | Ave. 35.1 | Cold & Reload Restarts | 13.4 | 19.8 |

TABLE C-7

Configuration B: Panels Off, Filters On

35 kV/m

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery 50% C.P. | 100% C.P. |
|---|---|---|---|---|
| 774 | 33.0 | Cold Restart | 7.5 | 15.7 |
| 775 | 34.7 | Cold Restart | 15.3 | 29.3 |
| 776 | 35.5 | Cold Restart | 34.4 | 37.0 |
| 777 | 35.7 | Reload Restart | 18.8 | |
| 778 | 35.8 | Reload Restart | 20.3 | 53.3 |
| 779 | 35.6 | Reload Restart | 12.7 | 39.4 |
| 780 | 35.3 | Reload Restart | 19.7 | 46.7 |
| 781 | 34.9 | Cold Restart | 29.7 | 36.0 |
| 782 | 35.5 | Cold Restart | 34.8 | 40.1 |
| 783 | 35.5 | Cold Restart | 8.0 | 31.9 |
| 784 | 34.6 | Cold Restart | 18.3 | 33.7 |
| 891-895 | Ave. 35.6 | Cold & Reload Restarts | 19.3 | |
| 896-909 | Ave. 35.9 | Cold & Reload Restarts | 37.0 | 59.3 |

TABLE C-8

Configuration C: Panels Off, Filters Off

35 kV/m

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery 50% C.P. | Time of Recovery 100% C.P. |
|---|---|---|---|---|
| 785 | 46.2 | Cold Restart | | |
| 786 | 47.7 | Cold Restart | 21.4 | 32.5 |
| 787 | 49.1 | Cold Restart | 15.3 | 40.1 |
| 788 | 47.9 | Cold Restart | 15.5 | 51.0 |
| 789 | 49.1 | Reload Restart | | |
| 790 | 48.7 | Reload Restart | 18.2 | 31.3 |
| 791 | 47.3 | Cold Restart | 16.0 | 61.0 |
| 850-853 | Ave. 46.1 | Reload Restarts | | |
| 854-864 | Ave. 46.4 | Cold & Reload Restarts | | |
| 865-877 | Ave. 47.4 | Cold & Reload Restarts | | |
| 878-890 | Ave. 47.2 | Cold & Reload Restarts | 48.2 | 65.3 |

TABLE C-9

Configuration C: Panels Off, Filters Off

48 kV/m

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery 50% C.P. | Time of Recovery 100% C.P. |
|---|---|---|---|---|
| 792 | 57.7 | Cold Restart | | |
| 793 | 62.9 | Reload Restart | 44.5 | 71.2 |
| 794 | 61.7 | Reload Restart | 35.7 | 63.0 |
| 795 | 61.6 | Cold Restart | 16.6 | 43.8 |
| 796 | 61.6 | Reload Restart | 43.0 | 51.6 |
| 797 | 62.3 | Cold Restart | 35.0 | 76.0 |
| 798 | 61.7 | Cold Restart | 44.0 | 45.0 |
| 799 | 64.2 | Cold Restart | 40.7 | 45.1 |
| 800 | 46.0* | Reload Restart | 17.0* | 53.0* |
| 801 | 61.7 | Cold Restart | 45.7 | 63.3 |
| 802-803 | 61.5 | Reload Restarts | 47.0 | 56.0 |
| 804-815 | Ave. 61.4 | Cold & Reload Restarts | 40.0 | 66.5 |
| 816-822 | 59.7 | Cold & Reload Restarts | | |
| 826-836 | Ave. 60.7 | Reload Restarts | 55.0 | |
| 837-849 | Ave. 60.7 | Reload Restarts | | |

TABLE C-10

Configuration C: Panels Off, Filters Off

* The Two Pulsers did not fire simultaneously

60 kV/m

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery | |
|---|---|---|---|---|
| | | | 50% C.P. | 100% C.P. |
| 910 | 35.8 | LTCs & LCMs SysB | | |
| 911 | 36.9 | LTCs & LCMs SysB | 6.5 | 16.0 |
| 912 | 35.4 | LTCs & LCMs SysB | 4.3 | 10.5 |
| 913 | 36.1 | LTCs & LCMs SysB | 3.0 | 12.4 |
| 914 | 36.3 | LTCs & LCMs SysB | | |

TABLE C-11

Configuration D: Panels On, Filters Off

35 kV/m

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery | |
|---|---|---|---|---|
| | | | 50% C.P. | 100% C.P. |
| 915 | 61.7 | LTCs & LCMs SysB | 28 | 28.7 |
| 916 | 62.3 | LTCs & LCMs SysB | 11 | 11.3 |
| 917-921 | Ave. 63.1 | LTCs & LCMs SysB | | |

TABLE C-12

Configuration D: Panels On, Filters Off

60 kV/m

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery 50% C.P. | 100% C.P. |
|---|---|---|---|---|
| 922 | 61.7 | LCM0 & LCM1 SysB | 5.0 | 7.0 |
| 923 | 59.3 | LCM0-1 & LCM1-1 SysB | | ** |
| 924 | 58.4 | LCM1 SysB (50% C.P.) | | 8.4 |
| 925 | | LCM1 SysB (50% C.P.) | | 6.0 |

TABLE C-13

**Configuration E: LCM Filters & Panels Off, Other Panels & Trunk Filters On**

**** Call Processing was not interrupted**

**60 kV/m**

## AESOP TESTING

| Pulse # | HEMP Field kV/m | System Response | Time of Recovery 50% C.P. | 100% C.P. |
|---|---|---|---|---|
| 930 | 61.4 | LCM0 & LCM1 SysB | 4.5 | 5.9 |
| 931 | 62.9 | LCM0 SysB (50% C.P.) | | |
| 932 | 62.9 | LCM0 & LCM1 SysB | 6.5 | 10.0 |
| 933 | 63.6 | LCM0 & LCM1 SysB | 7.0 | |
| 934 | 64.2 | LCM0 & LCM1 SysB | 8.3 | 13.7 |
| 935 | | LCM0 & LCM1 SysB | 7.0 | 17.3 |
| 936-955 | Ave. 63.3 | LCMs & LTCs SysB | | |

TABLE C-14

**Configuration F: LCM Filters and Panels Off,**

**Other Panels and Truck Filters On.**

**LCM Cable Looped Around Inside the Trailer**

**60 kV/m**